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PROSPECTS OF AN IRON AND STEEL INDUSTRY IN MADRAS

[Prepared by the late Dr. B. S. BALIGA, Ph. D. (Lond.), Curator, Madras Record Office, Madras]

WITH

A LAST CHAPTER ON PRESENT POSITION OF IRON AND STEEL INDUSTRY IN MADRAS

(Prepared by the Department of Industries, Labour and Co-operation)

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PREFACE

Iron and Steel had been manufactured in the Madras State from time immemorial though it had died out in the last century due to several factors. The people by adopting crude appliances and methods were able to produce from the iron ores of this State good quality iron and steel which were acclaimed as best and equal to foreign iron and steel. Struck by wonder on the skill of the people, a few enterprising officers of the East India Company, Geological Survey of India and other Government Departments and a few explorers made investigations from time to time from 1800 onwards relating to the industry. Mr. J. M. Heath, M.C.S., even manufactured iron at Porto Novo and other places by European methods. And they all have left their own accounts in that regard. But there is no single, continuous chronological account of the industry furnishing all important facts in order to explore the possibility of establishing an iron and steel plant in this State on modern methods. Even the " Brochure on Salem iron ores and their utilization " prepared in 1957 by the Industries Department does not meet the need although it furnishes a few technical details, etc.

2. To meet the need, the Government ordered the preparation of a Compendium on the industry and sanctioned the necessary staff. The late Dr. B. S. Baliga, Curator, Madras Record Office, who had agreed to undertake the work and who had proposed to prepare the compendium in six chapters, completed four chapters and a considerable portion of the fifth chapter (relating to the period 1947 to 1957), when, unfortunately, he suddenly expired on 21st September 1958. As there was no competent Curator to continue his work. I undertook to complete the Compendium on Iron and Steel Industry left unfinished by the late Dr. Baliga. In doing so, a departure has been made, viz., that instead of the 5th and 6th chapters contemplated by Dr. Baliga, a last (and fifth) chapter under the caption " The Present position of Iron and Steel Industry in Madras " furnishing an account of the industry from 1947 onwards, i.e., since the accession of the National Government upto date has been substituted.

3. The present Compendium attempts to furnish as briefly as possible, a chronological history of the industry restricted to facts as revealed from the records available. It does not attempt to express any views or suggestions except those of the experts and of the late Dr. Baliga. I, however, feel that it could form a reasonable basis for detailed study in the future, apart from its historical value. As the opinions of the experts themselves vary, this Compendium is intended for official use only.

4. The late Dr. Baliga had rendered meritorious and commendable service. It is a misfortune that he was snatched away at a premature age. I take this opportunity to place on record our deep debt of gratitude to him.

FORT ST. GEORGE,
2nd April 1959.

S. R. KAIWAR,
Secretary to Government, Industries, Labour and Co-operation Department.

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PROSPECTS OF AN IRON AND STEEL INDUSTRY IN MADRAS

CHAPTER I.

IRON ORE BEDS AND THE VIEWS OF THE GEOLOGISTS.

IRON AND STEEL constitute in these days the very bones and sinews of a nation alike in times of war and peace. They are essential not only for making all kinds of armaments but also for starting all kinds of industries, big as well as small. It is said that our country has always been deficit in steel and that the shortage has always been sought to be made up by imports. And it is hoped that its present demand of 4 millon tons of steel per annum which is only partly met to the extent of 3 million tons, by 1·3 million tons of production in the country and 1·7 million tons of imports, would be fully met when the three new steel plants, the Rourkela, the Bhilai and the Durgapur, each producing one million tons per year, come into operation in 1960–61. All the same, there is no reason why we should not increase our iron and steel output by seeking " fresh fields and pastures new " whenever they hold out promise. There is no reason why we should not investigate whether it is possible to start an iron and steel industry in our State, seeing that such an industry is bound to go a long way in assisting other industries projected under the Five-Year Plans.

2. There is, indeed, every reason to do so. Our State had an indigenous iron and steel industry from time immemorial till the close of the last century.[1]

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[1] Josiah Marshall Heath of Madras Civil Service—Application, dated 24th July 1824—Public Department Minutes of Consultations Nos. 586–581, dated 30th July 1824.

J. M. Heath—Remarks, dated 12th March 1828, on the steel-iron trade in England and on the expediency of establishing works in India for the supply of this article—Public Department Consultation No. 137, dated 23rd January 1833.

Edward Balfour (1855), Surgeon-in-charge, Government Central Museum, Madras—On the iron-ores; the manufacture of iron and steel and the coals of the Madras Presidency—Report on the Government Central Museum (1855)—pp. 2-40, 63-66, 117-124, 197-204, 216-223 and 228.

Henry F. Blanford of Geological Survey of India (1862)—On the Cretaceous and other rocks of the South Arcot and Trichinopoly districts, Madras—Memoirs of Geological Survey of India, Vol. IV, pt. 1, p. 36.

William King, Jr. and Robert Bruce Foote, both of Geological Survey of India (1864)—On the Geological structure of parts of the districts of Salem, Trichinopoly, Tanjore and South Arcot in Madras Presidency included in Sheet No. 79 of the Indian Atlas—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 374–377.

Sir Thomas H. Holland of Geological Survey of India—Preliminary report, dated 29th February 1892, on the iron-ores and iron-industries of the Salem district—Records of Geological Survey of India, Vol. XXV, part 3, pp. 145–149.

Dr. M. S. Krishnan and Sri N. K. N. Aiyengar of Geological Survey of India (1944)—The iron-ore deposits of parts of Salem and Trichinopoly districts—G.O. No. 4832, Development, dated 11th November 1944.

3. Our State had also, in the last century, an iron and steel industry run on European lines by Porto Novo Steel and Iron Company and East India Iron Company.[2] Both these industries have now disappeared; but both of them have left behind strong hopes of revival under modern conditions in the light of modern knowledge. The subject is, however, not free from controversy. While some experts have pronounced favourable opinions, others have pronounced unfavourable opinions. But still, the Government have, for various reasons, persisted in their belief that the revival is not only possible, but is necessary in the interests of our State.

4. The chief raw material needed for the industry is, of course, iron-ore. It is found in many places in our State. It occurs in North Arcot, South Arcot, Chingleput, Coimbatore, the Nilgiris, Pudukkottai, Salem and Tiruchirappalli. In North Arcot beds of magnetite-quartzite are to be seen near Gudiyattam, Katpadi and Vellore and in the Periyamalai near Polur.[3] In South Arcot, numerous exposures of magnetite-quartzite are to be found in the northern and eastern parts of the Kalravanmalai and some important beds have been noticed near Sankarapuram, Chinnatirupati and Madur Hill.[4] In Chingleput, a magnetite bed, three feet

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[2] E. Balfour (1855)—On the iron-ores, the manufacture of iron and steel and the coals of the Madras Presidency—Report on the Government Central Museum, pp. 8-9 and 35.

J. H. Garstin of Madras Civil Service (1878)—Porto Novo Iron Works—Manual of the South Arcot district, pp. 441-451.

William Maylor, Manager, East India Iron Company—Memorandum on the manufacture of iron and steel in Southern India—G.O. Ms. No. 1032, Revenue, dated 14th March 1896.

[3] E. Balfour—Report on the Government Centarl Museum, Madras, pp. 16-23.

R. B. Foote (1879)—Sketch of the Geology of North Arcot district—Records of Geological Survey of India, Vol. XII, pt. 4, p. 193.

Dr. M. S. Krishnan (1951)—Mineral Resources of Madras—Memoirs of Geological Survey of India, Vol. 80, Chapter XXIV, p. 146.

[4] H. F. Blanford (1862)—On the Cretaceous and other rocks of the South Arcot and Trichinopoly districts, Madras—Memoirs of Geological Survey of India, Vol. IV, pt. 1, pp. 36, 175 and 201.

[5] E. Balfour (1855)—Report on the Government Central Museum, pp. 35–40.

W. King Jr. and R. B. Foote (1864)—On the Geological structure of parts of the districts of Salem, Trichinopoly, Tanjore and South Arcot in Madras Presidency included in Sheet No. 79 of the Indian Atlas—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 279, 289, 293 and 294.

Dr. M. S. Krishnan (1951)—Mineral Resources of Madras—Memoirs of Geological Survey of India, Vol. 80, Chapter XXIV, p. 146.

thick, occurs about a mile south of the Sub-Collector's bungalow in Chingleput town.[5] In Coimbatore, magnetite of good quality is met with in the Doddankombai forest, Satyamangalam taluk, and magnetite-quartzite schists are seen near the Hallagomalai and in the Chinnamalai near Erode.[6] In the Nilgiris, some important iron ore bands are found near Karachola, one and a half miles west of Kotagiri on the spur of the Doddabetta.[7] In Pudukkottai (now a part of the Tiruchirappalli district), a bed of magnetite in gneiss occurs about one and a half miles north-east of Mallambatti.[8]

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[5] E. Balfour (1855)—On the iron ores; the manufacture of iron and steel and the coals of the Madras Presidency—Report on the Government Central Museum, pp. 63-64.

Dr. M. S. Krishnan (1951)—Mineral Resources of Madras—Memoirs of Geological Survey of India, Vol. 80, Chapter XXIV, p. 146.

[6] E. Balfour (1855)—On the iron-ores, the manufacture of iron and steel and the coals of the Madras Presidency—Report on the Government Central Museum, p. 65.

Dr. M. S. Krishnan (1951)—Mineral Resources of Madras—Memoirs of Geological Survey of India, Vol. 80, Chapter XXIV, p. 150.

[7] P. M. Benza (1836)—Notes on the geology of the country between Madras and Neilgherry Hills via Bangalore and Salem—Madras Journal of Literature and Science, Vol. IV, pp. 127.

E. Balfour (1855)—On the iron-ores, the manufacture of iron and steel and the coals of the Madras Presidency—Report on the Government Central Museum (1855), pp. 176–181.

H. F. Blanford (1858)—On the geological structure of the Nilgiri Hills (Madras)—Memoirs of Geological Survey of India, Vol. 1, pt. 2, p. 219.

Dr. M. S. Krishnan (1951)—Mineral Resources of Madras—Memoirs of Geological Survey of India, Vol. 80, Chapter XXIV, p. 150.

[8] R. B. Foote (1879)—On the geological features of the northern parts of Madura district, the Pudukkottai State and the southern parts of the Tanjore and Trichinopoly districts included within the limits of sheet 80 of the Indian Atlas—Records of Geological Survey of India, Vol. XII, pt. 3, p. 147.

Dr. M. S. Krishnan (1951)—Mineral Resources of Madras—Memoirs of Geological Survey of India, Vol. 80, p. 146.

V. Gopal of Geological Survey of India—Note on the iron-ore occurrence near Mallambati, Kulathur taluk, Tiruchirappalli district, Madras—G.O. Ms. No. 34, Industries, Labour and Co-operation, dated 4th January 1957.

5. But, nowhere does the iron ores occur more in abundance than in Salem [9], Tiruchirappalli. [10] It is this iron ore that has been considered worth exploiting; and it is again this iron ore that has been the subject of not a little controversy among the experts. All experts, however, agree that

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[9] J. M. Heath—Memorandum on Salem Iron Works—Journal of Asiatic Society, Vol. I, pp. 253-255.

E. Balfour—Report on the Government Central Museum (1853), pp. 198-199.

W. King Jr. and R. B. Foote (1864)—On the geological structure of parts of Salem, Tanjore, Trichinopoly and South Arcot districts in Madras Presidency—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 279–298 and 379–383.

Sir Thomas H. Holland (1892)—Preliminary Report, dated 29th February 1892, on the iron-ores and iron industries of the Salem district—Recorsd of Geological Survey of India, Vol. XXV, pp. 136–141.

G. Stokes, Collector of Salem—Memorandum No. 2784, dated 24th September 1894, on the iron-ores of the Salem district and the feasibility of developing their resources—G.Os. Nos. 420–422, Revenue, dated 4th July 1895.

C. S. Middlemiss of Geological Survey of India (1896)—Notes on the ultra-basic rocks and derived minerals of the chalk (magnesite) hills and other localities near Salem, Madras—Records of Geological Survey of India, Vol. XXIX, pp. 37–38.

C. S. Middlemiss of Geological Survey of India—Report, dated Udamalpet, 6th February 1898, on Kanjamalai quartz.-Magnetite beds—G.O. No. 123, Revenue, dated 1st March 1898.

Dr. Murray Stuart of Geological Survey of India (1919)—Note on the iron-ores of Kanjamalai, Salem, and on the possibility of smelting them electrically—G.O. No. 2268, Revenue (Special), dated 8th December 1919.

Dr. V. S. Dubey, Professor of Economic Geology, Benares Hindu University and C. Karunakaran of the same University—Preliminary report on the iron-ore deposits of Kanjamalai Hill, Salem district, and final report on the manufacture of steel from the Salem iron-ores—G.O. Ms. No. 2872, Development, dated 25th November 1939.

Dr. M. S. Krishnan and Sri N. K. N. Aiyengar, both of Geological Survey of India.—The iron-ore deposits of parts of Salem and Trichinopoly districts—G.O. No. 4832, Development, dated 11th November 1944.

[10] E. Balfour (1855)—Report on the Government Central Museum, Madras (1855), p. 228.

H. F. Blanford (1862)—On the Cretaceous and other rocks of the South Arcot and Trichinopoly districts, Madras Memoirs of Geological Survey of India, Vol. IV, pt. 1, pp. 36 and 201.

W. King Jr. and R. B. Foote (1864)—On the geological structure of parts of Salem, Tanjore and Trichinopoly and South Arcot [illegible] Madras Presidency—Memoirs of Geological Survey of India, Vol. IV, pt. 2, p. 295.

Dr. M. S. Krishnan and Sri N. K. N. Aiyengar—The iron-ore deposits of parts of parts of Salem and Trichinopoly districts—G.O. No. 4832, Development, dated 11th November 1944.

V. Gopal of Geological Survey of India—Note on the iron-ore occurrence near Mallambatti, Kulathur taluk, Tiruchirappalli district, Madras—G.O. Ms. No. 34, Industries, Labour and Co-operation, dated 4th January 1957.

the ore is chiefly magnetite and that it is available in large, in fact, immense quantities. But they differ as to the quality of the ore; while some say that it is high-grade ore, others say that it is low-grade ore. We need not state here the results of the numerous analyses made of this ore from time to time, from about the beginning of the last century till to-day. These will be stated in the subsequent chapters which deal with the attempts at exploiting the ores. But we must state here the views of the geologists who have examined the ore beds. These beds have been examined and described by Mr. Bruce Foote,[11] Sir Thomas Holland,[12] Mr. Middlemiss,[13] Dr. Murray Stuart,[14] and by Dr. M. S. Krishnan and N. K. N. Aiyengar,[15] all officers of the Geological Survey of India, as well as by Dr. V. S. Dubey,[16] Professor of Economic Geology, Benares Hindu University.

6. Mr. Bruce Foote who examined these beds along with Mr. William King in 1864, divides them mainly into five groups, namely, (1) the Kanjamalai group, (2) the Godumalai group, (3) the Talamalai-Kollimalai group, (4) the Singipatty group and (5) the Tirtamalai group, and holds out not a little promise from them.[17] The Kanjamalai group, says, Mr. Bruce Foote,[18] is one of the most accessible and important groups. It is situated near Salem and is therefore near the railway. It derives its name from a fine bold hill around which the iron beds are disposed of in a " concentric ellipse forming part of a great synclinal fold. The hill has three principal beds of magnetic iron ore, besides two others which

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[11] Report on the geological structure of parts of Salem, Tanjore, Trichinopoly and South Arcot districts in Madras Presidency included in sheet No 79 of the Indian Atlass—Memoirs of Geological Survey India, Vol. IV, pt. 2, pp. 279-298 and 379–386.

[12] Preliminary report, dated 29th February 1892 on the irone-ores and iron industries of the Salem district—Records of Geological Survey of India, Vol. XXV, pp. 135–159.

[13] Notes on the ultra-basic rocks and derived minerals of the chalk (magnesite) hills and other localities near Salem, Madras—Records of Geological Survey of India, Vol. XXIX (1896), pp. 37-38 Also Report, dated Ulumalpet, 6th February 1898, on Kanjamalai quartz-Magnatite beds—G.O. No. 123, Revenue, dated 1st March 1898.

[14] Note on the iron-ores of Kanjamalai, Salem, and on the possibility of smelting them electrically—G.O. No. 2268, Revenue (Special), dated 8th December 1919.

[15] Iron-ore deposits of parts of Salem and Trichinopoly districts—G.O. No 4832, Development, dated 11th November 1944.

[16] Preliminary Report on the iron-ore deposits of Kanjamalai Hill, Salem district, and final report on the manufacture of steel from the Salem iron-ores—G.O. Ms. No. 2872, Development, dated 25th November 1939.

[17] Report on the geological structure of parts of the districts of Salem, Trichinopoly. Tanjore and South Arcot in Madras Presidency—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 279–280 and pp. 379–386.

[18] Idem, pp. 279-280 and 379-386.

appear at the summit at the western extremity. The thickness of the two lowest beds, Nos. 1 and 2 will not be much below 50 feet, but the exact measurement is of little importance as for all practical purposes, the supply of the ore may be considered inexhaustible even if these two beds alone are taken into account Beds Nos. 3 and 5 are of equal size and are but a little inferior to Nos. 1 and 2. Bed No. 4 is, however, hardly more than 20 feet thick. Vast quantities of the ore of these beds have rolled down the hill sides, especially to the southward, where not only does the extensive talus consist mainly of it, but the fields from one to two miles from the hill are thickly strewn with it in the shape of rolled fragments of all sizes. Thousands and thousands of tons are thus scattered about and require merely to be gathered up without any mining operation. The richness of the beds is not constant throughout, but varies greatly from a rock which, to the naked eye, would appear to consist of ore to the extent of 7 parts in 8 (the eighth part being quartz) to one containing about half its bulk of ore; the great mass of the beds consisting of an intermediate quality in which the cubical and octahedral forms of the crystals of magnetic iron can occasionally be traced. The ore generally occurs in grains of various sizes lying in the planes of foliation and the grains have, when freely broken, a considerable metallic lustre: weathering, however, gives them a black or very dull purplish grey colour. The yield in the furnace, according to Mr. Maylor, the Manager of the Porto Novo Company, was about 55 per cent of iron pig, which is equivalent to 62 per cent of metallic iron of the finest quality. These beds were worked by people of the surrounding villages.''

7. The Godumalai group is considered equally important by Mr. Bruce Foote. This group of beds, he says,[1] takes its name from the Godumalai, '' a fine lofty hill rising in the middle of the Salem-Attur Valley. The beds may be traced from a point 7 miles east by north of Salem along the Godumalai ridge, then past Belur, north-eastward up the Nainamalai and thence along the eastern slopes of the Tenandamalai for many miles. The Godumalai hills themselves are about 4 miles long from west to east, their extreme width at the eastern end where it is broadest being 3 miles. On the northern side of the summit, there is a splendid precipice several hundred feet high. The bed is here shown in great magnitude forming the whole summit; it is here in places fully 100 feet thick and dips north at a high angle. At the western part of the ridge, just below the high crest, the quality of the magnetic iron is very rich and much iron sand was collected from the southern talus to supply the small

[1] Report, on the geological structure of parts of Salem, Tanjore Tiruchirappalli and South Arcot districts in Madras Presidency—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 280–284.

furnaces in several of the neighbouring villages; but at the eastern end, the bed is much poorer in iron. At the western end of the ridge the bed is much broken and consists of nothing but magnetic iron inter-laminated with quartz-rocks —the former predominating greatly and forming between three-fourths and five-sixths of the mass. The same degree of richness seems to continue pretty constantly for a mile to the west and as far as the summit of the hill to the east, after which there is a gradual diminution in the proportion of magnetic iron to about one-fourth of the mass. To the east, however, the bed, when ascending the Valoor hill, again becomes richer and shows a very fine ore containing about three-fifths of pure magnetite. It then again becomes poor but shows a fine rich ore on the Neighemullay plateau."

8. The Thalaimalai-Kollimalai group is, in parts, regarded as rich by Mr. Bruce Foote. The magnetic iron beds, comprising this group, he remarks,[20] " is spread over a wide area. They figure conspicuously in the vest horseshoe curve formed by the gneissic beds in the southern part of the Salem district, over the Kollimalais and the Thalaimalai, then get lost under the great spreads of cotton soil which cover the north-western side of the Tiruchirappalli district and re-appear again in the Pachaimalai hills. The principal iron beds of this group are four in number, three of them occurring about half way up in the total thickness of beds reckoned as belonging to the great curve and the fourth occurring at a much higher level but in obscure relation to the others. In the southern arm of the curve, two of these beds are traced from a little north of Thathaiyangarpettai westward to and along the most northerly ridge outlying from the Thalaimalai. Thence they extend westwards forming two well-marked wall-like ridges nearly to the Karuvattar river, and re-appear from under the alluvium and continue to a west-north-easterly course to a distance of about 12 miles. The third bed is an overlying one, not much developed in the southern arm of the curve but is best seen on the Kumarapatti hill a few miles to the south-south-west of Namakkal. The fourth bed occurs at Mahadevi near the south-eastern corner of the Kollimalais. The representative of the first two beds in the north arm of the curve is a great bed forming a ridge which commences at Vellalapatti and runs north-east by east for several miles, appearing conspicuously at Belukurichi ridges forming its crest for some distance until cut off by a great trap dyke and then running up the most north-westerly spur

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[20] Report on the geological structure of parts of the districts of Salem, Tiruchirappalli, Tanjore and South Arcot, Madras—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 284–288.

Le Fannu (1883)—A Manual of the Salem district in the Presidency of Madras, Vol. I, pp. 100-101.

of the Kollimalais and finally getting lost in the jungle. The third bed, the Kumarapatti hill bed, is represented in the northern arm of the curve by two fine rich beds forming the backbone of the Ullalapuram ridge, 5 miles north-west of Namakkal. These beds cross the Nainamalai hill, run up the western flank of the Kollimalais and appear as the magnetic iron beds on the high ridge north of Pylum. The Pylum ridge beds are very rich, nearly equal to the very richest parts of the Godumalai and Kanjamalai series and the iron obtained from them was held in high estimation, perhaps indeed the very highest of all manufactured in the Salem district. The fourth bed, the Mahadevi bed, is only very moderately rich."

9. The Singipatti group, observes Mr. Bruce Foote,[21] "is not specially remarkable for its richness. It lies four miles south of the Godumalai and comprises of three principal iron beds—separated from each other by intervening thick beds of hornblendic and quartzo-felspathi gneiss,—of which the west or the northern-most is the richest."

10. The Tirtamalai group, says Mr. Bruce Foote,[22] contains some rich beds. "This group is called after Tirtamalai, a fine bold mountain forming the extreme northern extremity of the Tenandamalai mass. It consists of two great, and in part, very rich beds forming the backbone and summit of the Tirtamalai ridge and a third bed 3 miles to the east on the banks of the Punniar river. The bed near the Tirtamalai pagoda is very rich in quality. Iron made from the ore of this bed was held in high estimation, the supply of ore here is unlimited, the bed being 50 to 100 feet thick. The third bed which occurs at Mondacooly on the Punniar, though small, is also a fine rich bed."

11. After thus decribing the principal series of iron beds—and it may be noted, some of them in glowing terms—and also some minor beds,[23] Mr. Bruce Foote offers [24] his general remarks thus. "The quantity of extremely rich iron ore available from the various sources may be said to be inexhaustible. Great part is obtainable by the very rudest methods of quarrying the surface; indeed mining would not be necessary for a very long time. If regular mining be adopted, many thousands of millions of tons of ore are at

[21] Report on the geological structure of parts of districts of Salem, Trichinopoly, Tanjore and South Arcot in Madras Presidency—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 288–289.

[22] Report on the geological structure of parts of the districts of Salem, Trichinopoly, Tanjore and South Arcot in Madras Presidency—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 289–290.

[23] Idem—pp. 291-297.

[24] Idem—page 297.

command. Nothing therefore but the want of fuel will prevent this part of India from being capable of supplying the world with never-failing quantity of the very best iron."

12. Mr. Thomas H. Holland (later, Sir Thomas Holland) who examined the Salem iron ore deposits in 1892, also gives [25] on the whole, an encouraging picture. According to him, " magnetite is by far the most abundant of the iron ores of the area. It occurs either in well-defined octahedral crystals (which frequently display polar magnetism) imbedded in chlorite schist. It also occurs with quartz, a schist in which crystals of magnetite ore are crushed out in the direction of foliation to a roughly almond shape, the proximtiy of the tapering points giving a lacunar appearance to the rock. Crystals of about one half to three-quarters of an inch in length and of this shape are common in the iron beds of Kanjamalai and of many other places in the district. All gradations in size are found down to an almost aphanitic rock in which the constituent minerals are, to the naked eye, indistinguishable as individual crystals—a type common to all the groups of iron beds. Bands of magnetite sometimes alternate with quartz, or with bands of quartz, and magnetite rich in the latter mineral, are found alternating with bands of the former, frequently contorted into fantastic patterns."

13. " The incipient expansion of the mass, accompanying the oxidation and hydration of magnetite ", says Sir Thomas Holland, " has, in many places, been sufficient to produce a rock which crumbles under the slightest blow or even between the fingers. These were the pieces exclusively used by village smelters on account of their friable nature. They are invariably found in the talus at the foot of the hills and probably are simply the more weathered representatives of the compact specimens occurring in the beds above. A further form in which magnetite occurs here is that of segregation from the main mass of the rock into cavities and pockets, as innumerable small crystals, in which the larger fragments frequently exhibit a distinct polarity of magnetism. Magnetite occurs also together with small crystalline fragments of quartz, felspar, hornblende, garnets and other minerals, as sand in the river beds, being derived from the dis-integartion of the numerous crystalline rocks within the area. In the trappean rocks, in granites and in the more basic gneisses, magnetite occurs in disseminated grains, but not in quantities sufficient for economic use."

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[25] Preliminary report, dated 29th February 1892, on the iron-ores and iron industries of the Salem district—Records of G.S.I., Vol. XXV, pp. 136-141.

14. "Magnetite", continues Sir Thomas, "may invariably be distinguished by its hardness. It is always attracted by and frequently is itself magnetic with well-developed polarity in large specimens. Besides being the most abundant, it is the richest ore of iron, containing, when pure, 72·4 per cent of pure iron, the remainder being oxygen ($Fe^3 O^4$). The ore which occurs in such abundance in the Salem district is the ore which has been used with success in the Scandinavian iron works. It was from this mineral smelted with charcoal that most of the famous Dannemora iron was produced. The Dannemora ore employed yielded on an average below 50 per cent of the metal, varying between 25 and 60 per cent, whilst in the Salem district, it is possible to obtain an almost inexhaustible supply of ore with an average of nearly 60 per cent of iron. The ore also contains little impurities like phosphorus and sulphur, and it was from this ore that Arunachala Achari made such good hunting weapons, etc."

15. Six representative samples of the Kanjamalai ores collected by Sir Thomas Holland were tested by the Imperial Institute, London, and these tests gave, on the whole, encouraging results. The analysis showed as follows :[26]

PERCENTAGE.

No.	Available. iron.	Silica.	Lime.	Sulphur,	Phosphorus.
799	68·95	1·04	..	0·16	0·13
815	70 06	1·72	..	0·20	..
873	63 57	8·89	..	0 29	..
874	66 96	3·17	..	0·10	..
812	36·44	46·95	..	0·10	..
813	35·73	48·45	..	0·29	0·27

The Director of the Institute observed[27] that the average percentage of iron was thus 56·95, the highest percentage being 70 and the lowest 36; that of the six samples, four were of excellent qualitiy and only two were inferior and that the four samples were undoubtedly suitable for conversion into pig iron by smelting on a large scale."

16. This remarkable picture of the Salem iron ores, especially the Kanjamalai ores, drawn by Mr. Bruce Foote and Sir Thomas Holland, was completely altered by the two later investigators, Mr. Middlemiss and Dr. Murray Stuart. Mr. Bruce Foote and Sir Thomas Holland, in essence, held that the ores were high grade and rich in magnetite and fit

[26] Memorandum by Prof. Wyndham Dunstan of the Imperial Institute, London, on the trials by Messrs. Bolckow Vaughan & Co., London, of samples of Salem iron-ore and Bengal Coal communicated in letter from Sir F. A. Abel, Honorary Secretary of the Institute to Under Secretary of State for India, R. No. 445-4, dated 11th November 1898—G.O. No. 7, Revenue, dated 4th January 1899.

[27] Idem.

to be expoited; Sir Thomas Holland also ventured to assert that the ores were even superior to the famous Dannemora ores of Sweden. Mr. Middlemiss [28] and Dr. Murray Stuart,[29] on the other hand, held that the ores were low grade, poor in magnetite and unfit to be exploited.

17. Mr. Middlemiss reported on the Kanjamalai beds in 1898. The Kanjamalai hill, he says [30] " is composed of a great series of regularly bedded gneisses, among which those containing hornblende, hypersthene and garnets are conspicuous. Its bands of magnetic iron ore are not pure magnetite, but the rock is a gneiss or schist containing a very large percentage of quartz. Some portions are fine-grained and some are coarse-grained. Whether fine or coarse, however, the general richness of the ore in the typical parts of the bands seems to be the same. These bands of quartz-magnetite rock appear to be regularly bedded with the other gneisses. There are three such bands; (1) the top band, a somewhat insignificant one forming a small ellipse of outcrop round the highest part of the mountain; (2) the middle band, some 500 feet or so above the mountain foot and about 30 feet thick, composed of the coarser quartz-magnetite rock, and (3) the lowermost band, about 70 feet thick, which forms a well-marked wall or dyke-like chain of spurs, almost all round the mountain and which is slightly richer than the middle band."

18. After thus describing the ore beds, he states that " in order to get an idea of the average richness of the better part of the quartz-Magnetite bands ", he took 32 specimens at intervals from different parts of the mountain, " each carefully broken out from the unweathered central portion of a fresh lump " and tested their specific gravities. " Most of the specimens ", he goes on to state, " were taken from the lowest band and some from the middle band ". He then gives the specific gravities of the 31 specimens, observes that " the average specific gravity is 3·51, that the lowest is 3·30 and the highest 3·80 " and asserts [31] that with

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[28] Notes on the ultra-basic rocks and derived minerals of the chalk (magnesite) hills and other localities near Salem, Madras—Records of G.S.I., Vol. XXIX (1896), pp. 37-38. Also report dated Udamalpet, 6th February 1898, on Kanjamalai quartz-magnatite beds—G.O. No. 123, Revenue, dated 1st March 1898.

[29] Note on the iron-ores of Kanjamalai, Salem, and on the possibility of smelting them electrically—G.O. No. 2268, Revenue (Special), dated 8th December 1919.

[30] Notes on the ultra-basic rocks and derived minerals of the chalk (magnesite) hills and other localities near Salem, Madras—Records of G.S.I., Vol. XXIX, 1896, pp. 37-38. Also report dated Udamalpet, 6th February 1898—G.O. No. 123, Revenue, dated 1st March 1898.

Report on the geological structure of parts of Salem, Tanjore, Tiru magnetite beds—G.O. No. 123, Revenue, dated 1st March 1898.

such specific gravities, "it is extremely unlikely that a higher yield of iron than 40 per cent will ever be obtained on a large scale from the Kanjamalai fields, whilst it is equally unlikely that the field wil ever sink as low 30 per cent."

19. This utterly unfavourable opinion, however, he qualifies by observing thus: "These percentages, it must be remembered refer to the whole rock as it would be quarried in the mass. The rock might no doubt be crushed and picked over, or other means might be adopted of separating the heavier minerals from the quartz when, of course, the cleaned ore would give a much higher percentage of iron. Only occasionally, in small pockets or as veins or local accretions (not more than a few inches across) do we sometimes find masses of pure or almost pure magnetite. But it would not be fair to include these in any estimate of the general richness of the beds. It is doubtless due to some such specimens as these having been gathered that some of the analyses of the Kanjamalai ore carried out at the Imperial Institute gave such abnormally rich percentage of iron (about 70 per cent) ".[32]

20. Mr. Middlemiss selected two tons of ore;[33] and the results of the tests by Messrs. Bolckow Vaughan and Company [34] as well as by the Imperial Institute,[35] London, showed that the ores were poor in iron. Messrs. Bolckow Vaughan and Company reported [36] that "the ore contained under 40 per cent of iron, that it existed as magnetic oxide of iron intimately mixed up with silicious matter, that the silica being 42 per cent was in greater proportion than iron", and that "such an ore was quite unsuitable for making merchantable pig iron." The Imperial Institute too found the ore low grade. A specimen of the ore analysed, the Director of the Institute said, had yielded the following results; "iron 38·74 per cent; insoluble residue (silica) 44·09 per cent; lime 0·365 per cent; sulphur 0·076 per cent; and phosphorus 0·14 per cent." This ore, the Director

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[32] and [33] Report, dated Udamalpet, 6th February 1898, on Kanjamalai quartz-magnetite beds—G.O. No. 123, Revenue, dated 1st March 1898.

[34] Letter, dated 28th July 1898, from Messrs. Bolckow Vaughan & Co., to Under Secretary of State for India—G.O. No. 548, Revenue, dated 22nd September 1898.

[35] Letter from Sir F. A. Abel, Honorary Secretary and Director, Imperial Institute, to Under Secretary of State for India, R. No. 445-4, dated 11th November 1898—G.O. No. 7, Revenue, dated 4th January 1899.

[36] Letter, dated 28th July 1898, from Messrs. Bolckow Vaughan & Co., to Under Secretary of State for India—G.O. No. 548, Revenue, dated 22nd September 1898.

pronounced, is extremely poor and quite unsuitable for smelting in the blast furnace." But, at the same time, he doubted, whether the specimen of the Kanjamalai ore selected by Mr. Middlemiss could be taken as a representative specimen at all, seeing that "Four out of the six specimens of the Kanjamalai ore selected as typical portions of the deposits by Sir Thomas Holland (to which we have already referred) were excellent samples of magnetite which would repay smelting." The Director, therefore, advised that "before any conclusion could be arrived at as to the value of the Kanjamalai deposit, it must be systematically sampled and analysed.[37] What happened as a result of these investigations we shall see elsewhere; but here, it must be noted that Mr. Middlemiss considered the Kanjamalai ore poor and that the analyses of the specimens which he sent to England also showed that the ore was poor and low grade.

21. Dr. Murray Stuart examined the Kanjamalai beds in 1919, and agreed totally with almost everything said about them by Mr. Middlemiss. In his report[38] he reviewed the history of the previous investigations and assailed the doubt cast by the Director of the Imperial Institute on the specimens sent for analysis by Mr. Middlemises. "I would", he said, "point out here that specimens representing portions of a deposit do not necessarily represent the deposit as a whole, and that the criticisms passed on Mr. Middlemiss's conclusions were not justified." He held the view, for which there is little basis, that "specimens of magnetite previously analysed, represented the magnetite of the magnetite schist, the quantity of it in the schist being accepted by Sir Thomas Holland to be the amount stated by Messrs. King and Bruce Foote. The sample sent in by Mr. Middlemiss was the first actual sample of the beds as a whole to be analysed, and it proved, as the samples now collected by me confirm that the estimate given by Messrs. King and Bruce Foote's report was too high." In stating thus, it will be seen that he forgot that the representative samples selected by Sir Thomas Holland, yielded in four out of six cases, high iron content as was reported[39] by the Imperial Institute.

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[37] Letter from Sir F. A. Abel, Honorary Secretary and Director, Imperial Institute, to the Under Secretary of State for India, R. No. 445-4, dated 11th November 1898—G.O. No. 7, Revenue, dated 4th January 1899.

[38] Note on the iron-ores of Kanjamalai, Salem, and on the possibility of smelting them electrically—G.O. No. 2268, Revenue (Special), dated 8th December 1919.

[39] Letter from Sir F. A. Abel, Honorary Secretary and Director, Imperial Institute, to the Under Secretary of State for India, R. No. 445-4, dated 11th November 1898—G.O. No. 7, Revenue, dated 4th January 1899.

22. Nor is this all. He described[40] the ore thus. "The ore is a quartz-magnetite schist, ranging in texture from a rock in which the lenticles of magnetite ore form one-half to three-quarters of an inch long to an almost aphanitic rock in which the constituent minerals are almost indistinguishable to the unaided eye. I carefully looked for the pockets, or veins, or local accretions of pure or almost pure magnetite mentioned by Mr. Middlemiss as occasionally occurring in the rock and was surprised to find how seldom they occur and how small they usually are. It was only after a long search that I found any at all and then they were of insignificant size." He said that he "did not agree with Messrs. King and Foote that some of the bands would appear to the naked eye to consist of ore to the extent of seven parts in eight". "His impression", he stated, was that "the rock consisted of rather less than half of its bulk of ore, and this estimate"; he asserted, "was supported by the analysis of bulk samples." And the three bulk samples he had taken, he said, by making a cut across the bed (the lowest bed) analysed in the laboratory of the Geological Survey of India gave the following results: in "No. 1 sample, 39.03 per cent of iron, in No. 2 sample, 38.6 per cent of iron and in No. 3 sample, 37·12 per cent" of iron. These results, he pointed out, showed "that Mr. Middlemiss's sample represented the average of the deposit has been established completely, and that the estimated richness of the beds given in Messrs. King and Bruce Foote's report was too high.

23. The gloom shed on the Kanjamalai beds by Mr. Middlemiss and Dr. Murray Stuart for a long time was chased away by Dr. V. S. Dubey. In 1937 Dr. Dubey examined the same beds and reported[41] as follows :—

"Kanjamalai has not been studied in detail by anybody, and the information about the occurrence of the vast deposits of iron ore on the hill is very meagre and indefinite. The magnetite ore deposits of the hill contain iron and silica in almost equal proportion. They are in a series of five parallel bands, totalling a thickness of at least 300 feet running practically round the hill with a few breaks and irregularities."

24. Band No. 1, the lowest band, is most easy to work. Its total length is not less than 6 miles and assuming its average height at 100 feet and width at 50 feet, the total amount of magnetite—quartz rock in it will be about 15 million tons, and the amount of magnetite in it will be about 7 million tons equivalent to 5 million tons of iron. It is easily

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[40] Note on the iron-ores of Kanjamalai, Salem, and on the possibility of smelting them electrically—G.O. No. 2268, Revenue (Special), dated 8th December 1919.

[41] Preliminary report on the iron-ore deposits of Kanjamalai Hill, Salem district—G.O. No. 2872, Development, dated 25th November 1939.

accessible for mining; and being situated at the bottom of the hill, a trolley line can be made to run throughout the length of this ridge.

25. Band No. 2, the next higher band, passes round the hill with a few breaks here and there. It is at least 4 miles long and its average thickness is about 50 feet. It dips very steeply, the dip being about 80°, but it should not be difficult to work it up to a depth of 50 feet as the rocks under it and over it are very hard and igneous ones. Its total amount of magnetite rock will be about 45 lakhs of tons, and magnetite 22 lakhs of tons, in order to exploit this band a system of inclined lines of railway will have to be worked.

26. Band No. 3, which is above band No. 2 is more than 4 miles long with an average thickness of more than 50 feet. It has about 33 lakhs of tons of magnetite rock, or about 16 lakhs tons of magnetite. In order to mine it, trolley lines can be run on its horizontal level and from this inclines can bring the ore down.

27. Band No. 4, which is above band No. 3, is three miles long and has an average thickness of at least 50 feet. The total amount of magnetite in it will be about the same as in band No. 3.

28. Band No. 5, which forms the topmost band, is about 2,000 feet above the plains. Its total length is not less than 1½ miles, and its average thickness is about 100 feet. It can be worked at least to a depth of 50 feet. Its total amount of magnetite rock will amount to 35 lakhs of tons, and its total amount of magnetite 17 lakhs of tons."

29. From this estimate, Dr. Dubey says, [42] "It is clear that the amount of iron ore in the hill is more than sufficient to last for several centuries." And from the analysis of 16 samples of the ore carried out at the Benares Hindu University, he says, "the average works out as 43·33 per cent SiO_2, 49·58 per cent Fe_2O_3, 1·82 per cent Al_2O_3, 2.08 per cent CaO, 1·91 per cent MgO, traces only of MnO, 1·62 per cent H_2O." "The specific gravity of the ore", he adds, "comes to 3·42". And as will be shown later, he firmly believed that with an ore like this an iron and steel industry can be started in our State. He also strongly recommended that the other iron ore areas of the Salem district should be thoroughly investigated.

30. The last and the latest investigations of the iron ore deposits of the Salem-Tiruchirappalli area were made by Dr. M. S. Krishnan and Sri N. K. N. Aiyengar. In their

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[42] Preliminary report on the iron deposits of Kanjamalai Hill, Salem district—G.O. No. 2872, Development, dated 25th November 1939.

report recorded by the Government in 1944, [43] they give a detailed description of the areas as well as an estimate of the quantities of the ore available in those areas. They also give the results of the analysis of the sample ores collected by them.

31. This is what they say [44] in general about the ores and the ore areas. "The magnetite-quartzite ores of the Salem-Trichinopoly-Arcot region constitute the most valuable group of iron ore deposits in our State. These ores assume an added importance in view of the fact that the development of the iron and steel industry must figure prominently in any scheme of pots-war industrial development. The area examined includes, parts of the Salem, Attur, Harur, Namakkal and Rasipur taluks of the Salem district and the Musiri and Perambalur taluks of the Trichinopoly district. The iron ore region in these areas is generally hilly and is divided into two equal portions by the Attur valley which extends in an easterly direction from Salem towards Cuddalore. The northern area comprises the Shevaroy, Chitteri and Kalrayan hills which spread over a distance of 50 miles from west to east; and the northern extension of these is the Tirthamalai. In the southern area, are the Kollaimalai and Pachaimalai as also the Talamalai and Bodamalai. The best known deposits are found in the Kanjamalai and Godumalai. There are no rivers of importance in those areas. The small streams traversing here join either the Cauvery in the west or south, or the Ponnaiyar in the north, or the Vellar in the east. Of the hills, only the larger hills like the Shevaroys, Kalrayan Hills, Chitteri Hills, Tirthamalai and Pachaimalai are wooded in these areas. The others support a thin forest or none at all. The areas are, however, traversed and surrounded by a number of fairly good roads, so that the road transport is not difficult here. As to the rail transport, the main broad gauge track of the Southern Railway connecting Madras and the West Coast passes close to the Shevaroys and the Kanjamalai, while the metre gauge branch line (from Salem to Vriddhachalam and Cuddalore) passes through the Attur Valley at the foot of the Godumalai and between the Chitteri and Kalrayan hills on the north and Kollaimalai and Pachaimalai on the south."

32. Dr. Krishnan and Sri Aiyengar trace briefly the history of the previous investigations and the analysis of the

[43] Iron-ore deposits of parts of Salem and Trichinopoly districts—G.O. No. 4832, Development, dated 11th November 1944.

[44] Idem.

ores and describe the general geology of the areas, and ore deposits [45]. The main deposits are—

(1) Kanjamalai;

(2) Attur Valley Godumalai; area north-east and south of Godumalai; Vellalakkundam hills including Perumamalai, Singipuram and Puduppalaiyam hills.

(3) Attur area—Tammampatti; Singiliyankombai;

(4) Tainandamalai and Chitteri hills; Belur and Sittilingi;

(5) Tirthamalai;

(6) Area between Namakkal and Rasipur;

(7) Kollaimalai; and

(8) Pachchaimalai and its spurs.

33. It is not necessary for our purposes to give here the details concerning these deposits, given by Dr. Krishnan and Sri Aiyengar. These will be found in their report in the Appendix I. We must, however, state here what they say about the nature, composition and reserves of the ores found in the various deposits. And this is what they state [46] :—

"The bands of ferruginous-quartzites found in the Salem-Trichinopoly region are associated with a series of schistose and gneissic rocks, the most prominent among which are chlorite and talc schists and amphibole and garnet bearing gneisses. They form a conformable series, though metamorphosed and often severely folded. The metamorphism has been responsible for the conversion of the ferruginous sediments, deposited perhaps as mixtures of ferric hydroxide and silica, into magnetite-quartzites. A varying amount of hematite is generally present in most of the bands, though occasionally it may be absent, or may attain a fairly high proportion. Quantitatively, however, hematite is unimportant as the average ore contains less than 10 per cent of the amount of magnetite present.

Texturally, there are three types of ore, banded, gneissic and fine-grained. The banded variety consists of alternate bands of magnetite and quartz. The thickness of the bands and the proportion of magnetite to quartz in the different layers vary from place to place. The average thickness of the layers is around 1/8 to ¼ inch, but individual layers may be thinner than 1/20 inch or as thick as one inch.

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[45] and [46] Iron-ore deposits of parts of Salem and Trichinopoly districts—G.O.No. 4832, Development, dated 11th November 1944.

The gneissic variety is akin to the banded one but the magnetite generally tends to be segregated into fairly coarse lenticular or augen shaped grains. This arrangement makes the banding irregular. The third type is granular or rather equigranular, being composed of a more or less uniform mixture of grains of magnetite and quartz. Most of the iron ores in the deposits may, however, be put under the banded variety, the gneissic and granular types being developed only locally."

About 30 samples were taken of the more important bands by making cuts across the bands and some of these were analysed in the Indian School of Mines, Dhanbad, and some in the laboratory of the Geological Survey of India, Calcutta. The analyses confirm the fact that the iron content of the ordinary ores is of the order of 35–40 per cent and the silica content about 50 per cent. There is little or no sulphur and the phosphorus is variable and in some cases high. There is some indication that phosphorus can be decreased during concentration. There is generally a small amount of titania (of the order 0·5 to 1 per cent) in most of the ores. Some alumina, lime and magnesia are also generally present [47].

The estimates of the reserves of ore in the various deposits are roughly as follows [48] :—

	TONS.
Kanjamalai	54,648,000
Godumalai	12,450,000
Perumamalai	10,428,000
Attur area	11,744,000
Chitteri Hills	55,416,000
Tirthamalai	47,520,000
Between Rasipur and Namakkal ..	33,924.000
Kollaimalai	67,452,000
Pachchaimalai	11,088,000
Total of all the deposits ..	**304,650,000**

For all the deposits (except one), a depth of 100 feet from the outcrop has been assumed. Some of them form hills several hundred feet high above the level of the adjacent plains and must contain ore to a much greater depth. As the deposits are all of bedded character, they can be assumed to be regular and more or less of uniform thickness. Hence,

[47] and [48] Iron-ore deposits of parts of Salem and Trichinopoly districts by Dr. M. S. Krishnan and Sri N. K. N. Aiyengar—G.O. No. 4832, Development, dated 11th November 1944.

in actual working, they can be expected to yield very much more than what the above calculations show probably anything up to four times the quantity [49].

34. Thus Dr. Krishnan and Sri Aiyengar held that in the Salem-Tiruchirappalli area, there are immense quantities of magnetic iron ore and this view is in agreement with the views of Mr. Bruce Foote and Dr. Dubey. But they also held that the quality of the ore is by no means high, that it contains only 35 to 40 per cent of iron, and this view is in variance with the views of Mr. Bruce Foote, Sir Thomas Holland and Dr. Dubey and is more or less in agreement with those of Mr. Middlemiss and Dr. Murray Stuart. In the matter of utilization of the ores, however, they held that the ores are easily amenable to concentration by magnetic methods to give 55 per cent of iron or even more [50]; and that such concentrated ores could be smelted either by charcoal in the blast furnace, or by electricity. This is not an altogether discouraging picture. We shall see later on, what the experts, other than these Geologists, have said about the utilization of the ores.

[49] and [50] Iron-ore deposits of parts of Salem and Trichinopoly districts—G.O. No. 4382, Development, dated 11th November 1944.

CHAPTER II.

THE INDUSTRY IN THE PAST.

Past is sometimes a pointer to the present; and a study of the past iron and steel industry of our State may very well make us ask, why such an industry cannot be revived at present. If people in the past with their limited knowledge and limited equipment were able to produce iron and steel of good quality, we, of the present generation, with our better knowledge and better equipment, should certainly be able to produce a more superior quality of iron and steel. This is what strikes any one, who has made a careful study of this industry.

2. There is evidence to show that Salem was famous for its manufacture of iron and steel from the days of Alexander the Great, to the days of Queen Victoria. There is evidence to show that for centuries together several other districts of our State also manufactured iron and steel of good quality. We have, however, no continuous history of this industry, but from the writings of early European travellers and other scientific men like Dr. Buchanan, Mr. Campbell, Mr. Benza, Mr. Newbold, and Dr. Balfour, it would appear that an iron and steel industry flourished well in our State from the dawn of history to the middle of the last century [1].

3. We have even evidence to show in the reports of Mr. Bruce Foote, [2] and Sir Thomas Holland, [3] not to mention the old Manuals and the Gazetteers, [4] that the Industry was

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[1] E. Balfour (1855)—On iron-ores, the manufacture of iron and steel and the coals in the Madras Presidency—Report on the Government Central Museum (1855)—pp. 2-40, 63-66, 124, 197-204, 216-223 and 228.

H. F. Blanford (1862)—Memoirs of Geological Survey of India, Vol. IV, pt. 1, p. 36.

W. King and R. B. Foote (1864)—Memoirs of Geological Survey of India, Vol. IV, p. 374.

Sir T. H. Holland (1892)—Records of Geological Survey of India, Vol. XXV, pt. 3, p. 145.

Dr. M. S. Krishnan and Sri N. K. N. Aiyengar—The iron-ore deposits of parts of Salem and Trichinopoly districts—Chapter III—G.O. No. 4832, Development, dated 11th November 1944.

Dr. M. S. Krishnan (1954)—Iron-ore, iron and steel—Bulletins of Geological Survey of India, Series A—Economic Geology, No. 9, Chapter I, pp. 3-4.

[2] On the geological structure of parts of the districts of Salem, Trichinopoly, Tanjore and South Arcot districts in Madras Presidency included in sheet 79 of the Indian Atlas—Memoirs of G.S.I., Vol. IV, pt. 2, pp. 374-377.

[3] Preliminary report, dated 29th February 1892 on iron-ores and iron industries of the Salem district—Records of Geological Survey of India, Vol. XXV, pt. 3, pp. 145–149.

[4] A Manual of the Salem district in the Presidency of Madras, Vol. I, by H. Le Fannu, M.C.S. (1883), p. 99.

Madras District Gazetteers, Salem, Vol. I, pt. 1, by F. J. Richards, I.C.S (1918), pp. 272-276.

carried on here and there till about the close of the last century. Dr. Balfour [5] mentions hundreds of villages of various districts where it was carried on about 1850 and Mr. Bruce Foote [6] and others speak of a number of villages where it was practised till about 1890.

4. This indigenous iron and steel industry seems to have been carried on, in all localities where iron ore was available. The men who practised it were mostly Harijans and iron-smiths and the methods they employed, both in mining and dressing the ore and in manufacturing iron and steel were mostly simple. Mr. Bruce Foote says [7] that usually "two methods" were followed in mining the ore. The first, which was "universally adopted, consisted of the digging of small irregular shallow trenches or holes—rarely more than three or four feet deep—generally in the talus of the beds, but sometimes also on the weathered outcrop from which the smallest and the most friable out-crops were collected and reduced to coarse sand by pounding, if not found in a state of sufficient communition. The second method of getting the ore was by making rude attempts at shafts, inclining according to the dip of the bed and joined together by still more irregular galleries all running on one line in the richest part of the bed, the greatest depth attained being about 15 feet below the surface, and the greatest diameter of the shafts being about 6 feet."

5. Sir Thomas Holland observes [8] that "in dressing the ore, the large fragments were crushed with a flat hammer, about 3 inches square; one man using the hammer, while the other was heaping the larger fragments into the central part of the pile. After sufficient material had been accumulated, the crushed rock was winnowed by pouring out a basket in strong wind. The heap so formed was divided into four portions. No. 1 consisting of large pieces, was to be recrushed. No. 2 was cleaned of its quartz by sifting in a shallow basket. Towards the end of the concentrating process the fragments which found their way to the lip of the basket would be compact grains of quartz and magnetite, and these were dropped back upon the pile for recrushing, instead of being thrown away with the quartz waste. When the magnetite was well concentrated in this manner, it was taken to the furnace. Sometimes, it was again recrushed and sifted before it was melted. No. 3 of the winnowed

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[5] Report on the Government Central Museum (1855), pp. 20-23, 36, 38, 66, 121-122, 204, 218, 228.

[6] Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 374–377.

[7] Idem—pp. 383-384.

[8] Preliminary report, dated 29th February 1892, on iron-ores and iron industries in the Salem district—Records of Geological Survey of India, Vol. XXV, pt. 3, p. 146.

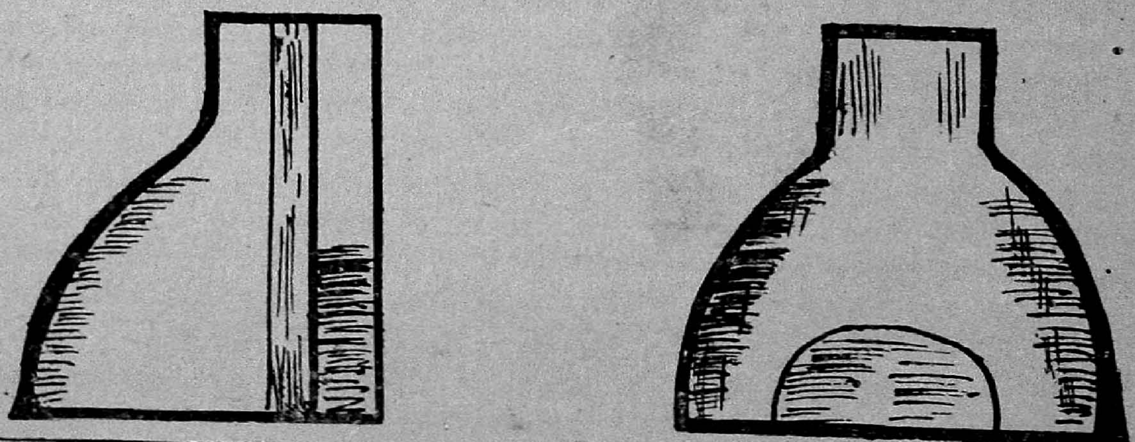
pile was composed of fine grains of quartz and magnetite and the concentration of this was brought about by washing it in the river. The workers, says Sir Thomas, were from practice, evidently aware of the fact that reducing the specific gravity of each mineral by 1, gives the magnetite a greater proportional weight over the quartz; for that was the principle upon which they adopted washing in preference to sifting for the finer particles. Portion No. 4 consisting almost wholly of limonite dust, was rejected as useless."

6. The methods employed for manufacturing wrought iron and steel have been described by various writers. We may mention here the accounts given by Mr. Bruce Foote, Dr. Krishnan and Sir Thomas Holland.

7. Mr. Bruce Foote [9] says that "the method of smelting the ores was very simple, the apparatus used was very cheap and the iron produced was of excellent quality. The shape and construction of the furnaces varied slightly but those most generally used were nearly cylindrical, tapering into an irregular cone at the top. The furnaces were constructed entirely of red clay mixed with sand; and they constantly required to have the inside renewed by fresh linings of clay which could not stand more than three or four days working. The height of the furnace varied from 3 to 5 feet with a diameter of the interior of about 9 inches to 1 foot. The furnace itself at the ground was about 2 feet wide and tapered sometimes from the ground and sometimes from about one-third to one-fourth of the height. Its walls were from 4 to 6 inches thick. Its front was for the most part nearly vertical and its back sloped considerably more than the sides see figure below:—

Figure.

Section and elevation of native furnace.



[9] On the geological structure of parts of the districts of Salem, Trichinopoly, Tanjore and South Arcot, Madras—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 375–377.

8. Inside the furnace the ground was generally excavated to a depth of about a foot to form a hearth for the bloom. A semi-circular opening from one foot to one foot two inches high was either left in the front wall or was subsequently cut into it while the clay was still moist. This was filled up with clay before the commencement of smelting.

9. The blast required for smelting was obtained by using two bellows, each made of a sheet or goat's skin, and worked by hand in the ordinary way by a man squatting in front of the furnace. The nozzles of the bellows were made either of thin sheet iron or tin plate, or sometimes of bamboos and these were inserted into a clay tuyere entering at the bottom of the front opening and carefully luted. The tuyeres reached to the bottom of the furnace, which was covered with charcoal dust to prevent the adhesion of the bloom. By using the bellows alternately a continuous blast was produced.

10. The furnace was first filled to the top, or very nearly so, with charcoal, which was ignited by means of a burning ember passed through the tuyere. As soon as flames issued from above, a small charge of the powdered iron ore, well moistened to make it cake together was introduced through the apex and covered with charcoal. This was followed by the successive charges of ore and fuel until the proper quantity of ore was in the furnace. The blast was now strongly applied and continued from two and a half to four hours according to the size of the furnace. The process was then considered complete; the semi-circular aperture in front of the furnace was opened and the bloom was removed. A number of heavy blows with a hammer or mallet were then given to the bloom to knock off as much as possible of the adhering oxide and the bloom was then cut half through with a hatchet and allowed to cool. The object of cutting open the bloom in this way was to exhibit the grain to the purchaser.

11. Charcoal was the only fuel used but different values were attached to the different woods for the purpose of charcoal, and frequently two or three different kinds were used at different levels in the furnace. It is important to note that no flux was used.

12. This bloom contained certain amount of slag inclusions and these were removed by meating while hot. The bloom was now ready to be worked into wrought iron or was further treated to make steel. This was done by the blacksmiths.

13. Steel-making in olden days described[10] by Dr. Krishnan evidently based upon an account given of the process by Mr. Heath (1839)[11], was as follows: "The wrought iron

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[10] The iron-ore deposits of parts of Salem and Trichinopoly districts —Vide G.O. No. 4832, Development, dated 11th November 1944.

[11] The Journal of the Royal Asiatic Society, Vol. V (1839), p. 397.

was carburised in crucibles made of clay and rice husk. The crucibles were usually about 6 inches long and 3 inches in diameter at their maximum. The charge consisted of pieces of wrought iron with which was also placed charcoal amounting to about 5 per cent by weight of the iron. The mouths of the crucibles were closed after the charge had been placed. Twenty or twenty-five crucibles were then kept on the slightly arched bottom of the furnace. Below this arched bottom, a bottleshaped cavity was left which served as the slag pit. After the first lighting up, charcoal for further combustion was added from above. Bellows supplied air through tuyeres which were, as we have already stated, located just above the neck of the pit. The centrally placed crucibles were ready for removal after smelting with continuous air blast for two hours. The crucibles at the sides were gradually moved to the centre and removed after a period known through experience. The molten contents of the crucibles solidified into conical ingots weighing around 10 lbs each. This process was the fore-runner of the cementation process in Europe. The product was the celebrated " wootz steel ".

14. Some points of interest which Mr. Heath mentions[12] in addition, are that the crucibles were made of red loam, which is very refractory, that the wood which was always selected to furnish carbon to the iron was *Cassia auriculata*, that the iron pieces and wood put into the crucibles were covered over with one or two green leaves; and that the leaves so used were invariably those of *Asclepias gigantea* or where they were not to be used, *Convolvulus laurifolius*.[13]

15. Steel so produced was celebrated for ages throughout the Middle East and Europe. It is said that the tools with which the Egyptians in ancient days covered their obelisks and temples of porphyry and syenite with hieroglyphics were made of this steel. It is also said that it was this steel (some 30 lbs.) that was presented as a valuable gift to Alexander the Great by King Porus.[14] Whether this was true or not, this much is certain. During the opening years of the nineteenth century, the excellence of this steel, which was called ' wootz ', caused quite a stir in the scientific world in England. It was then asserted, that wootz when properly treated becomes vastly superior to the best cast steel of Europe, that it is fit to be

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[12] The Journal of the Royal Asiatic Society, Vol. V (1839), page 397.

[13] J. M. Heath—The Journal of the Royal Asiatic Society, Vol. V (1839), p. 392.

[14] J. M. Heath (1839)—The Journal of the Royal Asiatic Society, Vol. V, p. 395.

Dr. M. S. Krishnan (1954)—Bulletins of the Geological Survey of India—Series A—Economic Geology—No. 9, Irone-ore, Iron and Steel —Chapter I, p. 3, Chapter VIII, p. 70.

manufactured into cutlery of every description and even surgical instruments; that it takes on a beautiful polish and does not appear subject to oxidization as the common cast steel; and that its specific gravity is 7·664 when imported and 7·852 when improved by hammering.

16. Wootz was manufactured in Salem evidently from practically the dawn of history till about the middle of the last century. Thereafter, it would appear, a different method of manufacturing steel came into vogue in Salem. Sir Thomas Holland says [15] that the conical ingots of wootz made by the *carburisation of wrought iron in crucibles*, had by 1890, given place in Salem to the flat cakes of steel produced by the partial removal by oxidization of the carbon in cast iron as in the open-hearth finery of Styria and Carinthia and in the ordinary puddling of pig-iron. The former steel (wootz) was made by carburisation while the latter steel was made by *de-carburisation*.

17. The latter method, that is, the de-carburisation method, he describes [16] as follows: "In the manufacture of wrought iron certain easily feasible beads of iron were produced and melted off as shots. These were in reality carburised particles or cast iron and it was from these that steel was made. The shots were first pounded in a stone mortar with a wooden pole shod with an iron ring—the rice pounder. By this process, the small particles of slag adhering to the shot were removed and the cast iron received an imperfect polish. The powdered slag material was separated by sifting in the ordinary manner in a shallow basket. A hole was dug in the ground about 1 foot deep and 1 foot in diameter. At one side, a semi-circular groove was excavated from the surface to the bottom of the pit. A large cake of soft clay served to divide this small excavation from the other part of the pit and the smaller chamber served as the finery in which the steel was made.

18. The bottom of this was first covered with a layer of dirty quartz obtained from sifting the crushed ore. On the heart of this quartz an ignited coal was placed and the small chamber was filled with charcoal. A tuyere, previously built in with clay partition pointed downwards at an angle of about 45° and received the nozzles of two goat-skin bellows by which a continuous blast was maintained. The shots were first wetted and thrown upon the charcoal, the amount used being governed by practice as in wrought iron smelting. The blast was continued for about half an hour, when the process of carburisation

[15] Preliminary report, dated 29th February 1892, on the iron-ores and iron industries of the Salem district—Records of Geological Survey of India (1892), Vol. XXV, pt. 3, p. 147.

[16] Preliminary report, dated 29th February 1892, on the iron ores and iron industries of the Salem district—Records of Geological Suvrey of India (1892), Vol. XXV, pt. 8, p. 147.

was complete. Then the tuyere and the clay partition were broken down for the removal of the steel cake. The cake was first slightly cooled by a dash of water and then hammered to remove the casing of slag which had formed around it. The workers were quite aware of the fact that if they continued the process too long, the resulting product would be of no more use than the ordinary wrought iron.

19. This indigenous iron and steel industry, that was carried on for more than 2,000 years, came to an end towards the close of the last century. The reasons[17] for this are stated to be mainly, (1) the increase in the price of charcoal and (2) the increased facilities in obtaining English iron since the opening of the railways. Even when the industry was tottering, it showed its intrinsic merit; for it was then that the famous iron-smith Arunachala Achari astonished the whole of India by making his celebrated hunting weapons out of indigenous steel produced in our State. But that was the last streak of its vanishing glory.

20. It must be stated here that modern writers have sometimes found fault with the way in which the industry was carried on. And the last of these writers, Dr. Krishnan says[18] that the processes employed "entailed an enormous wastage of time, heat, energy, ore and metal", that "since no flux was used, a large percentage of iron was lost in the slag", and "the furnaces were of poor construction and were wasteful in every way". But all this criticism is levelled, it should be remembered, in the light of modern knowledge and modern standards. Surely, the ancients cannot be judged by modern standards. That in spite of all drawbacks, they produced iron and steel which were pronounced by experts as of excellent quality, certainly redounds not a little to their credit. Nobody has denied this; in fact, everybody has, from the early days down to the present, admired the steel produced by them.

21. It was indeed this admiration that led some of the enterprising Europeans to start a modern iron and steel industry in our State. Early in the last century Mr. Josiah Marshall Heath, one of the civilians serving in our State, not a little struck by the excellence of the steel produced by the indigenous methods, began to think whether it would not be worthwhile to manufacture the same article by modern methods. He went on furlough to England, got the samples of the Salem ores

[17] R.B. Foote (1864)—On the geological structure of parts of the districts of Salem, Tanjore and South Arcot districts in Madras Presidency. Memoirs of Geological Survey of India Vol. IV, pt. 2, p. 377.

[18] The iron-ore deposits of parts of Salem and Trichinopoly districts—G.O. No. 4832, Development, dated 11th November 1944.

tested, found that they contained a high percentage of iron, came back to India, resigned the Civil Service (1825) and secured from the East India Company exclusive privileges for starting an iron and steel industry in 1833.[19]

22. The motives that actuated him in starting the industry were revealed fully in his letters.[20] They were as follows: " Steel was an essential article for national development; and yet, for the supply of steel, England was wholly dependent on Sweden and Russia. If any chances of war or any other cause were to intercept these supplies, England was bound to suffer incalculable injury. Dannemora iron of Sweden was indeed famous for steel making; but Madras iron ore which had been subjected to chemical analysis had been found as rich as Dannemora ore; in fact, " somewhat richer " even than the latter, the proportion of its constituent parts when freed from earthy matter being 72·3 per cent iron and 27·7 per cent oxygen. The only strong matter, associated with the Madras ore was pure silex, and all that was required to assimilate the materials, to those of Dannemora was the addition of some limestone which was abundant in the neighbourhood of the Madras ore area. Nor was this all. The imperfections in the ordinary kinds of steel iron arise from the ore containing sulphur, phosphorus, arsenic, copper or some other metallic admixture. The Dannemora ore was known to be quite free from any of these impurities: and so was also the Madras ore quite free from them. " I actually ", he said, " got the Indian (Madras) ore to England and had it made into pig iron and bar iron with the greatest care. The iron so made has been pronounced excellent and the steel instruments made of this ore have been declared to be in no way different from those made from the best cast-steel from Dannemora iron. Some have said that the Indian (Madras) steel is decidedly superior to any other description of steel." The 12,000 tons of foreign iron annually imported into England could easily be supplied from Madras and at a cheaper rate. And the iron works established in Madras would not interfere with the produce of England because English bar iron which was normally used in Madras for all purposes except steel making, could still be sold here with profit.

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[19] and [20] Appln. by J. M. Heath, dated 24th July 1824, for making available to him certain records regarding the iron and steel industry from the Government of India—Public Department Minutes of Consultations Nos. 580-581, dated 30th July 1824.

J. M. Heath's remarks, dated 12th March 1828, on the steel-iron trade in England and on the expediency of establishing works in India for the supply of this article—Public Department Consultation No. 137, dated 23rd January 1833.

Appln. of J. M. Heath, dated 8th August 1833, for grant of authority to raise minerals and to cut fuels from forests—Revenue Board's Consultations Nos. 2-3, dated 5th September 1833.

J. H. Garstin, M.C.S. (1878)—Porto Novo Iron Works—Manual of South Arcot district—pp. 441-445.

23. With idea such as these, and it will be noted, not with the idea of manufacturing steel in Madras, but with the idea of making pig iron for import to England, where it was to be converted into steel, Mr. Heath started [21] the Porto Novo Company and erected Iron Works at Porto Novo in 1830. He secured [22] the necessary privileges for mining the Salem and other ores and for cutting the fuel required for smelting. But it is one thing to plan and another to execute the plan. There is clear evidence to show that the main thing that stood in his way was finance, and not so much, the scarcity of fuel, as is sometimes supposed. The means at his disposal were only sufficient to enable him to prove that pig iron could be made without difficulty within the tropics, a result which previous to his operations had been pronounced impracticable.

24. A Committee [23] having been appointed by the Government to report on his results, he was given a large financial assistance. Confidence being thus established, in the merits of the venture, a few gentlemen at Madras were induced to come forward in 1833 to form the Indian Iron and Steel Company. New furnaces, forges and rolling mills were now erected at Porto Novo, and sometimes afterwards at Beypore also. There is evidence to show that this new Company "succeeded in manufacturing iron of a very superior quality which sold readily in England and India at high prices". But it too needed more finances to make the venture successful from the pecuniary point of view. It was, therefore, considered that the capital hitherto employed was not adequate to the full development of the undertaking as an investment or to the increasing demand for iron for railways and other public works and effective extension of the company's operations were strongly urged to meet the growing demands. Another new company was accordingly formed in London, in 1853 with a nominal capital of £ 400,000 and operations in Madras were carried on with renewed energy and vigour. Two subsidiary works were erected at Poolamputty in the Salem district and at Tiruvannamalai in the North Arcot district (then in the South Arcot district). In the case of this company too, there is clear evidence to show "that large quantities of very superior quality of pig iron" was manufactured by it and sent to England as ballast in cotton and tea ships. There is also evidence to show that this Company for a time made fair profits [24] .

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[21] J. H. Garstin, M.C.S.—Porto Novo Iron Works—Manual of the South Arcot district—pp. 445-451.

[22] Revenue Board's Consultations Nos. 2-3, dated 5th September 1833.

[23] J. H. Garstin—Porto Novo Iron Works—Manual of North Arcot district—pp. 445–451.

[24] J. H. Garstin—Porto Novo Iron Works—Manual of South Arcot district—pp. 448–451.

25. But very soon, two difficulties arose[25]. As long as the company could convey the pig iron to England as ballast in cotton and tea ships charged at ballast freight rates, it could make profits. But this mode of conveyance became difficult to procure, since considerable quantities of sugar and other dead-weight cargo came to be sent as ballast on those ships. This produced a financial crisis. The company also now tried to manufacture wrought iron and steel in their works in our State itself. And this, it found, by no means practicable on a commercial scale. In the words of Mr. Maylor[26], the manager of the company, "the repeated failures to manufacture wrought iron and steel upon a satisfactory commercial scale by the ordinary but laborious puddling process led to another financial crisis and induced the manager to report his inability to carry on the undertaking to a profitable issue". For a time, a silver lining appeared on the cloud. It was felt that the ill-success of manufacturing bar iron on a satisfactory commercial basis was mainly due to the difficulty of supplying the required large quantities of wood fuel and of carrying on the laborious work of puddling and reheating on a large scale with such fuel; and, as Sir Henry Bessemer was just then astonishing the world by exhibiting specimens of iron and steel direct from crude iron by simply forcing through the molten metal powerful jets of atmospheric air for a few minutes, it was suggested that this simple process was pre-eminently suited to be adopted in Madras. The Bessemer method was therefore adopted and the molten crude metal from the blast furnace was, to the surprise of all, converted into ingots of superior steel in a few minutes with only a small expenditure of fuel and labour. Reports of samples of tool and spring steel which were sent to the heads of departments in Madras and Bombay being very satisfactory, orders for supplies soon followed. But, the hopes of the company were again doomed to disappointment. It was observed that small-sized ingots produced were greatly honey-combed and when hammered out into merchantable bars showed numerous flaws —flaws which were then met with also in Sweden and Sheffield. It was also observed that large-sized ingots produced were much more perfect and sound but that the cost of labour of reheating and reducing them with steam hammers to small-sized bars made the business unprofitable. Attention was then turned to the desirability of executing orders for heavier classes of work such as, rails for the railway and wagon-wheel tyres, axles, etc.", but it was pointed out by the manager that "with wood fuel, native labour, and the heat of the climate",

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[25] Memorandum, dated 15th October 1895, on the manufacture of iron and steel in South India—G.O. Ms. No. 1032, Revenue, dated 14th March 1896.

[26] Idem.

it was impossible to successfully compete with English manufacture for such class of work, especially when freights from London were then as low as Rs. 50 to Rs. 30 per ton, and as "costly additions, renewals, alterations and repairs were urgently required", it was deemed advisable in 1864 to wind up the concern. This was done in 1867. Thus it was, that the attempts at establishing an iron and steel industry on European methods in our State came to an end.

26. It would be worthwhile to enquire why all these attempts failed. From all the evidence available, it is perfectly clear, that they failed for the following reasons. First and foremost, comes the want of finance, neither Porto Novo Company, nor the Indian Iron and Steel Company nor the East Indian Iron Company, found at their disposal sufficient finances to run the industry with success. Second, comes perhaps, the difficulty incidental to the export of pig iron to England to be converted into wrought iron and steel namely, the shipping freight charges; so long as these charges were low, the East Indian Iron and Steel Company could, and in fact, did make profit, but the moment they became high, exports failed to bring commercial success. Third comes, the want of fuel or charcoal. Now, about this reason which has been made much of by the modern writers, and experts, there is really not much evidence to show that the Porto Novo Company or the Indian Iron and Steel Company, failed for want of fuel. Neither of these Companies attributed their failure to this cause. They were given extensive privileges to cut fuel, and there is nothing to show that the want of fuel, forced them to wind up their concerns. In fact, as has been stated already, the rock upon which they split was finance. There is, however, ample evidence to show that the Indian Iron and Steel Company which came next in the field, found the fuel question a real difficulty [27]. That was because, as has been seen, they were the first to start manufacturing steel in our State; their predecessors manufactured only pig iron. And the manufacture of steel by the laborious puddling process, is said to have consumed large quantities of wood fuel.

27. These were, however, not the only reasons for the failure. Other reasons,[28] are also mentioned; and they are: (1) the want of labour; (2) the unhealthiness of the ore areas; (3) the difficulty of European supervision; and (4) the difficulty of transport. The want of labour was felt especially in the agricultural season. The unhealthiness of the ore-areas was said to be mostly because of the prevalence of malaria. The

[27] Memorandum, dated 15th October 1895, by William Maylor on the manufacture of iron and steel in Southern India—G.O. Ms. No. 1032, Revenue, dated 14th March 1896.

[28] Idem.

difficulty of European supervision was attributed to our hot climate. And the difficulty of transport was, of course, due to the lack of proper roads and railways in those days.

28. None of the reasons can now be said to stand in the way, if the industry were to be revived. Finance can be provided by the State. Shipping freight charges do not come into the picture, as the iron and steel made will be mostly for internal consumption. Fuel, i.e., wood fuel can be replaced by lignite and electricity. Labour can, it has been said, be commanded, to the extent necessary. Malaria, if any, existing now in the ore areas can be controlled by D.D.T. European supervision does not arise. And the transport has now been made more easy by roads and railways.

CHAPTER III.

ATTEMPTS AT REVIVAL IN THE LAST CENTURY.

The failure of the European Companies to establish an iron and steel industry in our State did not by any means extinguish the hopes for its revival. During the last hundred years attempts have been made again and again to revive the industry, sometimes by the officers sometimes by the private companies, but very often by the Government themselves. It is proposed to trace here the history of the attempts made in the last century and to trace in the next chapter the history of the attempts made in the present century.

2. The first attempt was made by Dr. Balfour, an eminent scientist, who in 1850, held the post of the Superintendent of the Government Central Museum. During the Cremian War when iron became scarce and its price went up, he made a detailed study of the indigenous iron and steel industry and submitted a voluminous report [1] to the Government (1854). It is not necessary to mention here the hundreds of villages where he found the industry in existence, nor is it necessary to describe here the methods by which industry was then carried on. But it is necessary to state here his views and recommendations for improving the industry.

3. This is what he stated. [2] In our State people make iron and steel which is " reported to be equal to the best products from Dannemora ", and the immense number of furnaces " found " all over the country " which yield " a vast amount of iron is a sure indication that, with all the waste, the people of this country are still preparing an article which the European furnaces cannot compete with." From the information available it is evident that, for all the smaller implements used in manufacturing and agricultural pursuits, the indigenous furnace are producing a steel iron infinitely superior to anything obtainable in England and which will stand a comparison with the best Swedish and Russian irons." The price of this indigenous iron is also much less than that of the iron manufactured by European methods; and, what is more, this iron is preferred by the people to English iron. Even as it is, more than half a million sterling worth of this iron is produced in our State. " Far superior to the ores of England which contain only 33 per cent of iron and equal to the best ores in the world, all that is wanting to the people

[1] Report on the Government Central Museum, Madras—On the iron-ores; the manufacture of iron and steel and the coals of the Madras Presidency (1855)—pp. 2-40, 63-66, 124, 175-182, 197-204, 216-223 and 228.

[2] Report on the Government Central Museum (1855)—pp. 6 and 11.

is the knowledge of working them on a larger scale and working them economically. What is required is that Madras shall be able to export to England and other countries the steel iron which is now chiefly obtained from Sweden and Russia. And this can be effected by introducing economy into the processes of smelting, by adopting a less wasteful mode of making charcoal, by improving the roads to the forests and the mines, by using rails and wagons on the slopes of the mountains, by employing more powerful bellows and larger furnaces and by teaching the smelters how to reduce the massive ores with a flux. The Government should investigate into all these matters and do what is possible to improve the indigenous industry."

4. But the Government at this time did nothing. The Cremian War soon came to an end (1856). England began to export more and more iron, our indigenous iron industry began to languish and die, and our people naturally began to go in for English iron. The subject, however, was revived once more when the officers of the Geological Survey, Mr. Bruce Foote[3] and Sir Thomas Holland[4], came and investigated the Salem ores and when they, as well as the other experts like the Director of the Imperial Institute[5], London, pronounced these ores superior even to the Dannemora ores. We have already seen in Chapter II what these geologists and experts have said about these ores. Sir Thomas Holland, in particular, it may be remarked, went even a step further than others and recommended in 1893 the need for investigating the possibilities of starting an iron and steel industry in Salem. He got details concerning the supply of fuel from the Salem forests. He thought that with the supply available, the industry could be started on a small-scale. He advised that, in order to expand the industry, experiments might be made to see whether, as recommended some years ago by Dr. Brandis, the charcoal made out of the fast growing trees like casuarina which grows in luxuriance on the coastal districts like Chingleput and South Arcot and Eucalyptus which grows on the Nilgiris could be profitably used for the industry. He also advised that an officer with sufficient metallurgical training might be sent to some Continental or American iron-smelting centres, where charcoal was used, to

[3] Report of the Geological structure of parts of districts of Salem, Tiruchirappalli, Tanjore and South Arcot in Madras Presidency (Sheet No. 79 of the Indian Atlas)—Memoirs of Geological Survey of India, Vol. IV, pt. 2, pp. 223–386

[4] Preliminary report, dated 29th February 1892, on the iron-ores and iron-industries of the Salem district—Records of Geological Survey of India, Vol. IV, pp. 135–159.

[5] Letter from Sir F. A. Abel, Honorary Secretary and Director, Imperial Institute to Under Secretary of State, R. No. 145-4, dated 11th November 1898—G.O. No. 7, Revenue, dated 4th January 1899.

study the processes both of charcoal burning and iron and steel making. [6]

5. His recommendations came in at a propitious time. It was at this time believed that the famous iron ore deposits near Bilbao in Spain from which about four million tons of ore used to be annually exported to England and other countries was about to be exhausted. [7] It was at this time also that several new factors seemed to favour the starting of an iron and steel industry in the South; and these were the construction of the railways which connected the Salem district with the east and west coasts and with the Singareni coal field. The cheapening of ocean transit and the improvements by inventors generally in iron and steel making plant and furnaces are effecting considerable reduction in the cost of production. [8] The Government, therefore, lost no time in applying to the Government of India for the appointment of a Special Officer for the investigation of the mineral resources, especially the iron resources of our State. They said that they would indeed be glad if the services of Sir Thomas Holland were placed at their disposal for this purpose. [9] Nor is this all. They asked[10] the Board of Revenue to report on the feasibility of working the ores.

6. The Board of Revenue referred[11] the matter to the Collector of Salem and Mr. G. Stokes, the then Collector, submitted [12] in 1894 a memorandum outlining the prospects of the industry. In this memorandum, he observed [13] as follows :—

There are rich "iron beds considered to contain magnetic iron of superior quality in Salem" which have attracted the

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[6] Preliminary Report, dated 29th February 1892, on the iron-ores and iron-industries of the Salem district—Records of G.S.I., Vol. XXV, pt. 3 (1892), pp. 146-159.

Note, dated 10th November 1893, sent to Mr. G. Stokes, Collector of Salem—Mr. Stoke's Memorandum No. 2784, dated 24th September 1894, to Government on the iron ores of the Salem district and the feasibility of developing their resources—G.O. Nos. 420–422, Revenue, dated 4th May 1895.

[7] Note, dated 10th November 1893, by Sir T. H. Holland to Collector of Salem on the development of the iron resources of Salem district—Memorandum No. 2784, dated 24th September 1894, from Mr. G. Stokes, Collector of Salem—G.O. Nos. 420-422, Revenue, dated 4th July 1895.

Report, dated 2nd May 1896, of Jeremiah Head on the practicability of conducting an iron industry at or near Salem—G.O. Ms. No. 3506, Revenue, dated 1st September 1896.

[8] Report of J. Head mentioned above.

[9] G.O. Ms. No. 563-564, Revenue, dated 26th June 1893, .

[10] G.O. Ms. No. 420-422, Revenue, dated 4th July 1895.

[11] G.O. Nos. 420–422, Revenue, dated 4th July 1895.

[12] and [13] Memorandum by G. Stokes, No. 2784, dated 24th September 1896, on the iron ores of the Salem district and the feasibility of developing their resources—G.O. Nos. 420 422, Revenue, dated 4th July 1895.

attention of geological explorers from the time of Buchanam (1800) down to the present day. Professor Turner in a paper read by him recently at the conference of the Iron and Steel Institute in England speaks of the Salem ores thus: 'In this region, iron ore of the best quality (magnetite) is to be obtained in quantities which can only be estimated in thousands of millions of tons, and though scarcity of fuel and the cost of transit have hitherto prevented these deposits from being worked on a large scale, it is scarcely possible that such obstacles will prove insurmountable. Sir Thomas Holland who examined these ores in 1892 says that the ores are without question undoubted in quantity and quality also. The writings of the geologists point to a consensus of opinion that the Salem ores are infinitely superior to those obtainable in England and will stand a comparison with the best Swedish and Russian ores. It is also an undoubted fact that steel of perhaps the very best quality was made from it and used by the late Arunachala Achari. Auxiliary ores such as chromites, titanium and aluminium, useful for the manufacture of iron, also occur in the district.

But the crux of the subject is how best to convert these ores to profitable account commercially. It has been said by the Forest Department that "the Kanjamalai and the Tirthamalai beds are conveniently situated to be worked from the standpoint of charcoal supply. It has been also said that the past attempts failed for want of fuel supply. Fuel supply is thus an all important factor. Coal is not produced in the district; nor can it be transported from Northern India at an economical rate. Charcoal, therefore, is the only fuel with which iron making can go on, if the industry is to be revived".

7. An estimate of the charcoal available for smelting the ores of Kanjamalai and Tirthamalai, has been prepared by the Forest Department. "The ores of Kanjamalai beds can be advantageously carried by the railway from the Arianur and Salem railway stations to Kadayampatti near the foot of the surrounding forests. Similarly the ores of the Tirthamalai beds can be brought to Hanumantirtham about seven miles distant for the manufacture of iron. The Tirthamalai, unlike the Kanjamalai, is itself sufficiently situated in the midst of forests but, to bring the part of the Javadi hill forests within the supplying area of the furnace, the ores will have to be brought to Hanumantirtham. The northern slope of the Kanjamalai may be connected with the Salem railway station, only 7½ miles from the western end of the hill, by restoring the already existing branch road at a small cost. The southern side of the hills will have to be connected with the Arianur railway station by opening from both the ends (eastern and western) of the slopes two feeder roads, 5 and 3 miles long

respectively. The road connecting the Tirthamalai with Hanumantirtham is 7 miles, while the road from Samulputty railway station to Hanumantirtham is only 11 miles."

From the figures supplied by the Forest Department, "it is seen that for smelting at Kadayampatti, 75,500 acres of forest in round number are available within the radius of 10 miles and 134,000 acres of forests within 16 miles. Similarly for smelting at Hanumantirtham, 65,500 and 110,300 acres of forests are available within the radius of 10 and 16 miles respectively. Deducting 25 per cent on account of the rocky and poorly stocked nature of forests in certain places, we get for both the beds put together, 105,700 acres within 16 miles as the extent of available workable forests thus:

—	Within 10 miles acres.	Within 16 miles acres.
(1)	(2)	(3)
1 Kadayampatti Centre	56,600	99,500
1 Hanumantirtham Centre	49,100	82,700
Total ..	105,700	182,200

The next question is how much wood may be obtained from the available forests. Adopting the well-known rates of production, taking half a ton an acre of wood, and taking the acknowledged rates of conversion, viz., one ton of wood to produce one ton of iron wrought up and 17 cwts. or 17/20 ton of charcoal to smelt one ton of pig iron, the quantity of iron which might be produced is shown below:

Smelting locality.	Areas of forest available for supply of fuel.	Quantity of wood to be obtained from (2).	Quantity of charcoal to be produced from the wood (3).	Out turn of iron: Wrought iron.	Out turn of iron: Pig iron.
(1)	(2)	(3)	(4)	(5)	(6)
Within 10 miles—	Acres	Tons	Tons	Tons	Tons
Kadayampatty Centre.	56,600	28,300	5,660	1,617	6,659
Hanumantirtham Centre.	49,100	24,450	4,910	1,403	5,776
Total ..	105,700	52,850	10,570	3,020	12,435
Within 16 miles—					
Kadayampatty Centre.	99,500	49,750	9,950	2,843	11,706
Hanumantirtham Centre.	82,700	41,350	8,270	2,363	9,729
Total ..	182,200	91,100	18,220	5,206	21,435

From this it is seen that fuel in neither of the centres is sufficient to manufacture 10,000 tons per annum, if the fuel-supplying area is restricted to 10 miles. If it is, however, extended to 16 miles, the Kadayampatty centre alone can smelt 11,706 tons of pig iron. Sir Thomas Holland says that "it would scarcely pay to work a modern blast furnace with an outturn of less than 10,000 tons of pig iron per annum." It follows, therefore, that there is sufficient quantity of fuel for working a blast furnace at Kadayampatty centre and that for this the forests lying within the radius of 16 miles should be indented upon.

These are only rough estimates. Before the industry is started, detailed estimates of fuel will have to be worked out, and the labour conditions of the area will have to be investigated to ascertain whether sufficient labour is available at reasonable rates. Other considerations are these. Singareni coal will not coke and therefore will be of no use to the Salem ores. These ores will have to be smelted with charcoal. And, as the Madras Railway passes through, or in the vicinity of forest clad areas in the North Arcot and Coimbatore districts, it should be ascertained, whether a large supply of charcoal from these districts cannot be added to the supply of local forests. In view of all these, a Special Officer should be appointed to work out the details of a scheme for starting an industry. It is clear that it is possible to smelt a large quantity of iron in the Salem district. The question is whether such an operation would be a commercial success".

These views and recommendations of Mr. Stokes were fully endorsed[14] by Sir Thomas Holland. Sir Thomas Holland also observed[15] that "it must not be forgotten that the quality of the Salem ore gives it a great natural advantage especially in the manufacture of malleable iron and steel, and that, as it was said that the Spanish mines were approaching exhaustion, it might even pay to export the iron ore to England". The Board of Revenue and the Government, however, deemed it enough, if the memorandum of Mr. Stokes were given wide publicity in India as well as in England[16] and a copy of it were sent to the Secretary of State for his consideration.

8. Meanwhile, nothing came of the proposal to appoint a Special Officer to investigate the iron resources of our State.

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[14] Note, dated 10th November 1893, on the development of iron resources of Salem district—G.O. Nos. 420-422, Revenue, dated 4th July 1895.

[15] Idem.

[16] G.O. Nos. 420-422, Revenue, dated 4th July 1895.

In 1896, the Secretary of State sent [17] a report of Mr. Jeremiah Head of the Institute of Mechanical Engineers, England which put a damper over the whole enquiry. Mr. Head advised [18] that in the existing circumstances commercial success could not be expected from attempts either to send Salem ores in bulk to England or to make iron and steel on the spot in Salem with the charcoal from the neighbouring forests or with the coke from the Singareni or Barakar field.

9. This is how he viewed the subject. The factors favourable at present for the establishment of an iron industry in Madras (Salem) are said to be, " (1) the construction of the railways which now connect the Salem district with the east and west coasts and with the principal cities north and south and with the Singareni coal field in Hyderabad; (2) the recent improvements made in iron and steel making plant and furnaces whereby the cost of production is everywhere much less now than it was 25 years ago; (3) the anticipated exhaustion before long of the ore deposits near Bilbao in Spain, from which about 4,000,000 tons are annually exported to Great Britain and elsewhere. These circumstances together with the cheapening of ocean transit which has taken place in recent years may now, it is contended, make possible an ore export trade from Madras to British and other European ports.

Now, there is no doubt whatever of the occurrence of great abundance of excellent magnetite iron ore (Fe_3O_4) in the neighbourhood of Salem. This is testified by Mr. Stokes, Mr. Bruce Foote, Sir Thomas Holland and Mr. Le Fannu in his Manual. Taking the Kanjamalai beds alone, there are three principal beds of magnetite which would yield about 900,000,000 tons, which is equal to the total ore exports from Bilbao for 225 years. The average yield of the ore as estimated by Mr. Maylor, the General Manager of the East India Iron Company, is 55 per cent in pig iron, which is equivalent to 51 per cent of metallic iron. Sir Frederic Abel, the Director of Imperial Institute, has recently analysed three samples of the ore and found that they contain 70·064, 63·461 and 68·89 per cent, or, on an average, 66·34 per cent of metallic iron (Fe.). Two of these samples contained no phosphorus and one 0·131 per cent of phosphorus. Then sulphur contents were 0·20, 0·29 and 0·16 or, on an average, 0·22 per cent. All this indicates an ore very rich in iron.

[17] Despatch No. 10, Revenue, dated 2nd July 1896, from the Secretary of State for India—G.O. No. 3506, Revenue, dated 1st September 1896.

[18] Report, dated 2nd May 1896, of Jeremiah Head—G.O. No. 3506 Revenue, dated 1st September 1896.
Idem.

The impurities of the ore, viz., silica, sulphur and phosphoric anhydride are low and there is but little moisture in it. The ore is sufficiently pure for use in the manufacture of Bessemer pig iron. It closely resembles the higher grades A and B of magnetite ores from Gellivara in the north of Sweden which are now being exported to England.

Notwithstanding all this, it should not be forgotton that there are similar ores near Britain, and that all these will have to be exhausted before the Salem ores are thought of. The exhaustion of the Bilbao deposits in Spain has proved a myth; firstly because several new deposits have lately been opened out there and secondly because the number of known but unworked deposits there is very great. Moreover, in other countries, notably Sweden, there is an unlimited quantity of ore of at least as good a quality ore as that of Kanjamalai. The cost of transport of the Kanjamalai ore to England would also work up high.

As to whether an iron industry can be established in Salem on Styrian and American methods by using charcoal with any prospect of success, " the Styrian and American methods have for their object solely, the manufacture of charcoal pig iron, a product which is then sold or applied to various purposes such as conversion into steel in Bessemer converters or Open Hearth furnaces, the manufacture of high class iron castings and malleable castinge. This involves a blast furnace plant which must be supplied with iron ore, charcoal and a suitable flux. The quantity of sufficiently rich and pure iron ore near Salem is, as has already been said, unlimited. Suitable fluxes in the same locality are abundant, but the determining consideration is the supply of charcoal fuel. It is the scarcity of fuel, that was one of the main difficulties of the East India Iron Company. It has, therefore, to be clearly ascertained whether sufficient fuel is available for starting the industry. Singareni coal is unfit for coking and therefore for smelting. Barakar coal will have to be transported from Bengal and hence will prove costly."

10. With views and arguments such as these, Mr. Head, came to the following conclusions:[20] " (1) that the prevalent belief in the possibility of carrying on an iron and steel industry in Salem with success is founded on the circumstances that rich and pure magnetite ore exists in unlimited quantities and that the people have from time immemorial

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[20] Report, dated 2nd May 1896, on the practicability of conducting an iron industry at or near Salem, etc.—G.O. No. 3506, Revenue, dated 1st September 1896.

made excellent iron and steel from it, though in small quantities and with crude appliances; (2) that the repeated efforts made in the past failed mainly because of the difficulty of obtaining a continuous and suitable supply of fuel; (3) that an ore containing in the bulk 63 per cent of iron and not more than 8 per cent in silica and with other impurities low enough for Bessemer pig, might be put f.o.b. Madras for Rs. 7 per ton, but that this taken at the existing value in England (16 shillings 6 pence per ton) would, under the most favourable circumstances, involve a loss of Rs. 3-11-0 or 4 shillings 3 pence per ton. That the idea of an export trade in Salem magnetite to European ports must, therefore, be given up as impracticable; (4) that, whereas Rs. 50 to Rs. 60 per ton is said to have been the cost price of charcoal pig iron made in the Salem district and delivered at Madras in the past, it is certain that that price left a serious loss and that it would not be impossible to manufacture under Rs. 66-0-10 delivered at the same port even under the most favourable conditions; (5) that, at this cost price, competition with imported pig iron suitable for ordinary purposes such as, foundry castings or iron or steel manufacture would not be possible. It is, therefore, better for the people of South India to import the iron and steel they require than to attempt to produce it from indigenous materials either at Madras or in the Salem district, except on a small scale for exceptional uses; (6) that, although Kanjamalai charcoal pig iron might be sent to England at about the existing price as imported from Sweden, there is little to encourage efforts to establish such trade; (7) that the substitution of Singareni coal at Kanjamalai, or of Barakar coal, would not improve the chances of success; and (8) that, it is not practicable to conduct an iron industry at or near Salem upon the methods pursued in Styria and America where charcoal is used for smelting.''

11. Of these conclusions of Mr. Head, the only one with which the Government agreed [21] was that which related to the impracticability of exporting the Salem ores to England. His other conclusions were challenged [22] by the Government. They adduced facts and figures to show that the Salem iron could be profitably sold in England. They also adduced evidence to show that an iron industry based on charcoal could, in fact, be established in Salem, though on a small scale. And they quoted the authority of Major Mahon, [23] the Superintendent of the foundry and steel factory at Cossipore, to

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[21] Despatch No. 3, Revenue, dated 24th March 1898, to the Secretary of State for India—G.O. Nos. 168-168-A, Revenue, dated 22nd March 1898.

Idem.

[23] Report, dated 5th May 1894 on the manufacture of iron and steel in India—G.O. Nos. 221-222, Revenue, dated 30th March 1897 —Also Mahon's letter, dated 17th September 1896, containing his comments on Head's report—G.O. Ms. Nos. 221-222, Revenue, dated 30th March 1897.

show that pig iron could possibly be manufactured at Calcutta out of the Salem ores and Bengal coal. But, they could not achieve much. they could not make out a strong case for starting an industry in Salem. Mr. Head's conclusions whether right or wrong, still found favour with the Government of India and the Secretary of State. And, as if this were not enough, Mr. Middlemiss's damaging report on the Kanjamalai ores, to which we have already referred in Chapter II, now came in and wrecked all hopes for starting the industry. Nevertheless, the Government succeeded in sending some samples of Kanjamalai ores and Sanctoria (Bengal) coal to England for ascertaining whether the former could not be smelted with the aid of the coke produced by the latter.

12. Unfortunately, this experiment proved a failure; firstly because the samples of ore selected by Mr. Middlemiss could not by any means be regarded as true samples, and secondly because the samples of coal selected in Bengal were, before they were transhipped to England, allowed to deteriorate for months at Howrah. The results were, as might be expected, Messrs. Bolckow Vaughan and Company who tested the samples reported [24] thus: "Forty tons of coal were tested in Leasingthorne Colliery. After washing out 15 per cent shale, etc., the coal was coked in Coppee coke ovens. The coke produced is soft and friable and quite unsuitable for smelting purposes on that account alone, but as it contains a large proportion of ash (23 per cent), no furnace can be worked with such material. In another experiment made in the Auckland Park Colliery also the coke, though more satisfactory, fell far short of what is considered to be fair smelting coke. The ash was a little under 17 per cent. "The 2½ tons of Salem ore we have carefully examined and must say that we should never think of charging such material into our blast furnace". Mr. Stead of Messrs. Pattison and Stead has reported that the ore contains under 40 per cent of iron and that it exists as magnetic oxide of iron intimately mixed up with the silicious matter. The silica in the ore is in greater proportion than iron, viz., 42 per cent. Such an ore is quite unsuitable for making merchantable pig iron. Magnetic concentration of the ore, such as is done in America, may not be possible, and if possible, may be found costly."

13. This unfavourable opinion on the Salem ores and Bengal coal did not in the least deter, either the private companies or this Government or the Government of India from pursuing again the subject of exploiting the Salem ores.

[24] Report, dated 28th July 1898—G.O. No. 548, Revenue, dated 22nd September 1898.

Messrs. Turner and Macfadyen and Company addressed the Secretary of State to permit their representative, Mr. Hugh C. Mc-Neill to examine the Salem ores and report upon them. They said that the experiments made by Messrs. Bolckow Vaughan and Company would not be said to be conclusive. They pointed out that coke made from Bengal coal was actually used by some firms to smelt Bengal iron ore. And they remarked that the adverse opinion expressed on the suitability of the Salem iron ore to make merchantable pig iron must have been due to some error made in the selection of the samples sent to Middlesborough. They observed that there were several official reports to show that ores of superior quality and of unlimited quantity exist in Salem and that there was also a certainty that pig iron of good quality made from that ore had been sent to England. And they advised that the subject should not be left in uncertainty.[25]

14. A similar opinion was expressed by Professor Dunstan, the Director of the Imperial Institute, London[26]. We have already referred to this in Chapter II while speaking of Mr. Middlemiss's report on the Kanjamalai beds. We may, however, repeat it again here where we deal with the analysis and attempts at exploiting the ores. The Director stated that of the six representative samples of iron ores of Kanjamalai collected by Sir Thomas Holland in 1892, and tested in the Imperial Institute, four were found to be of excellent quality, their percentage of iron being 68·95, 70·06, 63·57 and 66·96 respectively; that these samples were undoubtedly suitable for conversion into pig iron by smelting on a large scale; that a sample selected by Mr. Middlemiss in 1896 and tested in the Institute, gave only 38·74 per cent of iron, a percentage similar to the one reported by Messrs. Bolckow Vaughan and Company; that this sample was indeed extremely poor and quite unsuitable for smelting in the blast furnace; that the sample of Bengal coal analysed in the Institute also furnished poor results substantially in agreement with those obtained by Messrs. Bolckow Vaughan and Company; but that, neither the unsuitability of the ore, nor the unsuitability of the coal, could be said to have been established. The Director remarked that Mr. Middlemiss's sample could not be regarded as a typical sample of the ore, as Sir Thomas Holland's typical samples gave different results and a different interpretation. Nor could, he remarked, the analysis of the samples of the

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[25] Letter No. R. & S. 1786, dated 21st September 1898, to Under Secretary of State for India—G.O. No. 4529, Revenue, dated 19th November 1898.

[26] Letter from Sir F. A. Abel, Honorary Secretary and Director, Imperial Institute, to Under Secretary of State, R. No. 445-4, dated 11th November 1898—G.O. No. 7, Revenue, dated 4th January 1899.

Bengal (Sanctoria) coal, made in Middlesborough and in the Institute be taken as correct, as the analysis of 53 samples of the Bengal coal made recently in the Institute in some other connection, had shown that several samples of that coal could be easily converted into coke suitable for smelting iron. He, therefore, advised that further investigation should be made both as to the quality of the ore and the quality of the coal.

15. The Government of India themselves stressed the necessity for further investigation to the Secretary of the State, by observing as follows :—

" The results of the analysis of the 2½ tons of ore made by Messrs. Bolckow Vaughan and Company are hardly less favourable than anticipated. We understand that in practice charges for the blast furnaces of any iron factory that might be established in Salem would certainly be made from " picked " ore. The process of " picking " secures at a comparatively trifling cost at Madras the exclusion of inferior qualities of the ore and will no doubt be freely resorted to by any Company that may be established in future.

The sample sent to England for analysis should, therefore, have been taken from " picked " ore. But it appears from Mr. Middlemiss's report, which we did not receive until the 2½ tons had been already despatched, that this was not the case and that, instead of being a sample of the ore which would be selected by manufacturers, the consignment consisted of " average specimens of the whole rock as it would be quarried in the mass ". We were, therefore, prepared for the intimation that the analysis of the samples forwarded were so much less favourable than those made from specimens of Kanjamalai ore by Sri Frederick Abel at the Imperial Institute Laboratory in 1896 which gave an average of over 70 per cent of iron, than some analyses recently made at the Cossipore Chemical Factory which gave an average of 64 per cent of iron than the results obtained during the whole period from 1829 to 1861 when the ore was worked regularly and gave averages varying from 51 per cent to 61 per cent of iron. We consider, therefore, that the 2½ tons, on which experiments have been made, cannot be regarded as a fair sample of the ore which would in practice be selected for reduction in any iron works that may hereafter be opened and that the determination of the available quality of such ore may be better

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[27] Letter R. No. 445-4, dated 11th November 1898, from Sir F. A. Abel, Honorary Secretary and Director, Imperial Institute, London, to Under Secretary of State—G.O. No. 7, Revenue, dated 4th January 1899.

[28] Despatch No. 29, Public Works, of 1898, dated 3rd November 1898 —G.O. No. 686, Revenue, dated 19th November 1898.

left to the experts who will no doubt be employed by Syndicates who have supplied for licences to prospect the tract for minerals. We have, therefore, decided that it will be inadvisable to continue experiments on sample ores selected by Government Officers, for we apprehend that, whatever may be the result of such experiments, it will be difficult to satisfy the promoters of a private enterprise that the selection has been conducted in such a way as to fairly indicate the commercial value of the Kanjamalai iron fields.

With regard to the experiments made to ascertain the coking qualities of the Giridi coal (Bengal or Sanctoria coal), we consider the results obtained, though inconclusive, are distinctly hopeful. Better results would surely have been obtained if the coal had been cleaner. Major Mahon, to whom we sent the results of the experiments made, attributes the high percentage of ash in the coke to the fact that the ash forming constituents were not washed out of the coal as thoroughly as many be possible.

For these reasons and in view of the importance of the issues involved in these experiments, we are strongly of opinion that a further trial should be made under the supervision of an officer interested in a successful result. Major Mahon who intends to go to England may be placed on deputation and instructed to make arrangements for another series of experiments on Bengal coal.

We have ascertained that the consignment of coal sent to England by the Madras Government, from which the experiments were made by Messrs. Bolckow Vaughan and Company, was selected from coal which had been stored at the Howrah depot from November to March and which had not itself been specially selected with a view to these experiments. We are informed that exposure to weather has a detrimental effect on the coking qualities of coal and we think it not unlikely that the weathering which the samples sent to England had undergone, was one cause of the unfavourable results of the experiments. Major Mahon, who has visited the Giridi Colliery and the works of the Bengal Iron and Steel Company at Barakar and who has discussed the subject with the Mining Engineer of the Bengal Coal Company and the Manager of the East Indian Railway Collieries, says that the analysis of the coal as reported by Messrs. Bolckow Vaughan and Company pointed either to a want of the proper precautions in the selection of the coal or to an error in the results reported. In accordance with Major Mahon's recommendations we have ordered a fresh consignment of 100 tons of coal to be despatched to England; they have been taken from Jherria, Giridi and Sanctoria coal fields ".

16. While in this manner the Government of India impressed upon the Secretary of State the need for investigating further the coking qualities of Bengal coal, the Government of Madras impressed [29] upon them the need for investigating the possibilities of the magnetic concentration of the Salem ore, a process which was then being tried with success in Sweden. They said that the experiments made by Messrs. Bolckow Vaughan and Company were not conclusive, and that the unfavourable results of these experiments at the same time could not but discourage private capitalists from attempting to exploit the Salem ores. They stated that the expert sent by Messrs. Turner and Macfadyen and Company who had examined the Kanjamalai beds had given as his opinion that, although moderate quantities of ore of good quality might be obtained by hand-picking and possibly larger quantities after extensive borings, it would be necessary to adopt some system of magnetic concentration, if operations were to be carried on on a large scale and in an economical manner. And they suggested that, as such magnetic concentration of the ores was then being carried on successfully on a large scale in Sweden, they might be permitted to send to Sweden about 200 tons of Salem are, to be treated by the magnetic process under the supervision of Major Mahon, who had already evinced a keen interest in the subject of the manufacture of Indian iron.

17. Unluckily neither the proposal of the Government of India, nor the proposal of the Government of Madras carried any weight with the Secretary of State, and, therefore, nothing came of them. Nor did anything come of the enthusiasm shown by Messrs. Turner and Macfadyen and Company. Messrs. Best and Company, their representatives, were indeed given a prospecting licence for three years over the Kanjamalai, hill, with the right of a mining lease for 30 years of the whole of the hill subject to the condition that within five years from the date of the prospecting licence, a Company should be formed with a working capital fully paid up of £1,00,000 [30] But Messrs. Best and Company, for some reasons which cannot be ascertained, lost interest in the matter.

18. Meanwhile, however, Major Mahon submitted a report[31] to the Government of India which proved conclusively that Bengal coal could produce coke suitable for iron smelting. In this report he stated [32] that the Bengal Iron and Steel Company

[29] G.O. Nos. 136-137, Revenue, dated 23rd February 1899,

[30] G.O. No. 234, Revenue, dated 19th March 1901.

[31] Letter No. 218-170-2, dated 26th January 1905, from Government of India, Department of Revenue and Agriculture (G. and M.), to Madras Government—G.O. No. 269, Revenue, dated 23rd February 1905.

[32] Idem.

smelted iron ore with coke made from Bengal coal and that the East Indian Railway Company had made coke at Giridi which could be used for any foundry or furnace work.

19. This was the position in the last century and, from the various discussions that then took place, certain facts emerged and compelled attention. One was that, in view of the vast difference of opinion as to the quality of the Salem ores, between Mr. Bruce Foote and Sir Thomas Holland on the one hand and Mr. Middlemiss on the other, there was a real necessity for a fresh and thorough investigation of the ore beds. Another was that, Bengal (or as we should say to-day Bihar) coal could be utilized to produce coke suitable for iron smelting. The third was that, it was possible to start an iron and steel industry, though on a small scale, in Salem with the aid of charcoal supplied from the local forests or from the forests of the Western Ghats and the coastal districts, like Chingleput and South Arcot. And the fourth was that it was worth examining to see whether magnetic concentration of the ores as was carried out in Sweden could not be carried out in Salem.

CHAPTER IV.

ATTEMPTS AT REVIVAL TILL 1947.

Hopes always persist whenever they are founded on substance and not on mere shadows. And the hopes for the revival of the iron and steel industry in our State, founded as they were on a number of posibilitie conidered in the last, century have, despite many disappointments, continued to agitate the mind of the Government in the present century. In recent days, the discovery of lignite in South Arcot as also the advancement of knowledge and technique in magnetic concentration, electrical smelting, etc., have opened up fresh vistas of hope and promise. As it is, however, not possible to deal with the whole subject here without making this chapter unduly long, we shall describe in this chapter the attempts made till 1947, till the establishment of the National Government, and reserve the consideration of the attempts made thereafter, to the next chapter.

2. To proceed with our narrative, in 1914, Messrs. E. Gaudart and Company of St. Elizabeth Iron Works, Pondicherry, applied for and obtained a mining lease over 4,369 acres in the Kanjamalais for working the iron ore. [1] They extracted a small quantity of the ore and sent [2] ten tons of it to France for magnetic concentration test. The report was favourable but the out-break of the First World War prevented the working of the concession and the lease was cancelled in 1916 [3]. As soon as the war was ended, however, an agitation was made in the Reformed Legislature for conducting an economic and industrial survey with reference to the development of mining industries. And in this connexion, Mr. Innes, I.C.S., the then Director of Industries, submitted a note on the possibility of developing the Salem iron ores with power derived from the proposed Hogenkal and Mettur Hydro-electric Schemes. [4]

3. Mr. Innes estimated that the Hogenkal and Mettur schemes when completed might be able to supply a sufficient quantity of electrical energy to smelt the iron ores of Salem.

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1 G.O. No. 1278, Revenue, dated 1st May 1912, and G.O. Ms. No. 1425, Revenue, dated 15th May 1913.

2 Note by Mr. C. A. Innes, I.C.S., Director of Industries on the possibility of developing the Salem iron ores with power derived from the Hogenkal Hydro-electric Scheme—G.O. No. 387, Revenue (Special), dated 4th March 1919.

3 Note by Mr. C. A. Innes, I.C.S. on the possibility of developing the Salem iron ores with power derived from the Hogenkal Hydro-electric Scheme—G.O. No. 386, Revenue (Special), dated 4th March 1919.

4 Idem

He pointed out that electric iron-smelting was well established in Sweden; that the quantity of iron that could be made with a given supply of charcoal was three times as much in the electric furnace as in the blast furnace; and that the target electric furnace in operation was of 4,000 E.H.P. but that the tendency was to build them from 4,000 to 6,000 E.H.P. He, however, remarked that the Salem ore which was throughout regarded as high grade ore, had, since Mr. Middlemiss's report been regarded as low grade ore, that therefore, it might perhaps be necessary to concentrate the ore to incrase its iron content and that, in any case, it would be desirable before proceeding further to ask an officer of the Geological Survey to take fresh samples of the ore for testing it for magnetic concentration.[5]

4. Mr. Innes's hopes, hopes, as well as the hopes of the Government were, however, dashed to pieces by the report [6] of Dr. Murray Stuart, the officer of the Geological Survey deputed to collect the bulk sample of the Kanjamalai ores with a view to considering the possibilities of electric smelting and magnetic concentration. As we have seen already in Chapter II, Dr. Murray Stuart agreed with Mr. Middlemiss that the ore was low grade. The samples that he selected and tested in the laboratory of the Geological Survey of India, he said, contained only the following percentage of iron.

Number of sample	perentage of iron.
1	39·03
2	38·60
3	37·12

He also said that the samples collected by Dr. W. Chowdhry on behalf of Messrs. Gaudart and Company of Pondicherry, in 1914, gave also similar results when analysed by Dr. Schulten of Calcutta. And as to the treatment and smelting of the ore by electric power, he pronounced his opinion as follows :—

" As the distance of the ore deposit from the coal-fields of India or from the coast, prohibited the ordinary smelting of the ore, and as the local supply of sufficient charcoal for this purpose had also proved to be impossible, the suggestion has been brought forward that the ores might be treated and sfeuted euectrically, it being possible to obtain electric power

[5] Note by Mr. C. A. Innes, I.C.S.—G.O. No. 387, Revenue (Special), dated 4th March 1919.

[6] Note on the iron ores of Kanjamalai, Salem, and on the possibility of smelting them electrically—G.O. No. 2268, Revenue (Special), dated 8th December 1919.

from a proposed hydro-electric power scheme on the borders of Madras and Mysore. The treatment of the ores under this scheme would consist of (1) crashing the ore, (2) magnetic concentaration, (3) briquetting the concentrated magnetite with charcoal and limestone, and (4) smelting in an electric furnace. Experiments already carried out on the ore have shown that the preliminary crushing must be very fine to give a satisfactory result. The first point to be considered is whether sufficient charcoal can be obtained locally. The smallest electric smelting furnace that is estimated to pay is the one turning out 60 tons of iron per day. Now, the electric smelting of iron ore requires approximately 17 cwts. of charcoal for every ton of iron produced. Therefore, the daily production of 60 tons of iron would involve the consumption of 51 tons of charcoal and this would mean the carbonization of at least 204 tons of wood daily. The provision of this 204 tons of wood daily, therefore, would mean the cutting of 612 acres of forest reserve every day; and the wood would have to be cut up, carbonised and the resulting charcoal conveyed to the smelters daily. A forest area of at least 224,092 acres would be necessary for a continuous supply of charcoal.

Since the charcoal is scarce. the crushing, briquetting and all the other necessary operations. would have to be done by electric power. The amount that would be consumed in this way would be considerable. The magnetite schist is exceedingly hard and considerable electric power would be consumed in the satisfactory crushing of it. Moreover. the electric smelting of iron ores is also just coming into commercial practice. It is now being done in Sweden. But it has been pointed out that electrical smelting of iron ores becomes commercially sound only when one horse-power year of electrical energy costs less than 2·3 tons of coke."

5. After stating this, Dr. Murray Stuart gave his final verdict in these words: "Owing to the low grade of the Kanjamalai ore—practically three tons of which would have to be quarried, crushed and treatd in a magnetic concentrator for every ton of iron produced, its extreme hardness and the large area from which wood for charcoal would have to be collected, I do not consider that the electric smelting of the Kanjamalai iron ores lies within the bounds of present commercial possibility." [7]

6. The Government published this report for the information of the general public and, as may be expected, whatever chances there were of developing the ores, now completely

[7] Note on the iron-ores of Kanjamalai, Salem, and on the possibility of smelting them electrically—G.O. No. 2268, Revenue (Special), dated 8th December 1919.

disappeared for a time. Thus, Messrs. Abbas Hussain and Company who came forward to work the ores in 1917 withdrew from the scene the moment this report was published in 1919.[8] A sense of frustration was felt everywhere, even by the Government themselves. They now felt that it was no use depending upon the officers of the Geological Survey to develop the industries in our State; and they approached more than once, the Government of India to sanction the post of a Provincial Mineralogist who would be in a position to study in detail the possibilities of developing the iron as well as the other industries in our State. But the Government of India brought forward all sorts of arguments against this proposal, which therefore had to be postponed in 1922.[9] The matter, however, did not rest here. In 1936, the Director of Industries got some samples of the Salem ores and sent them to the Director, Geological Survey of India and the Travancore Minerals Company for magnetic separation. The Travancore Minerals Company doubted whether magnetic separation could be successful and reported that their commercial magnetic separators which were of high intensity type lifted the whole of the sample and therefore made the experiment impossible, while the Director, Geological Survey of India, reported that the samples sent to him were too poor, too low in iron content to be crushed and magnetically separated. The latter even remarked that the cost of crushing and magnetic separation of such low grade ore " would be so high that it would be a waste of time and money to investigate further."[10] This needlessly discouraging report of the Director of Geological Survey, compelled our Government again (1939) to consider the question of appointing a Provincial Mining Geologist. But again, the question had to be dropped.[11]

7. Meanwhile, the events moved in a different direction. In March 1937, at the suggestion of the Director of Industries, Dr. V. S. Dubey, Professor of Economic Geology of the Benares Hindu University, was employed to examine the Salem ore deposits. He submitted two reports to the Government, saw great prospects in the development of an iron and steel industry in Salem, and urged further detailed investigation in regard to several matters.[12] We have already seen in Chapter II, what he has had to say about the ore-beds and how he observed that the Kanjamalai beds alone contained

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[8] G.O. No. 2268, Revenue (Special), dated 8th December 1919.
[9] G.O. Ms. No. 1580, Development, dated 26th August 1921.
[10] G.O. Nos. 1073-1074, Development, dated 3rd July 1936.
[11] G.O. Ms. No. 1113, Development, dated 28th April 1939.
[12] G.O. Ms. No. 2872, Development, dated 25th November 1939.

vast quantities of high grade magnetite, containing on an average 55·30 per cent of Fe_3O_4 We may now see here what he has had to say about the utilization of these ores.

8. In his first report he stated thus[13] "Most of the rocks in Kanjamalai are similar in composition and in most of them the silica ranges between 42 per cent and 50 per cent, while the amount of Fe_3O_4 lies between 45 per cent and 55 per cent. The amount of CaO and MgO in the rock depends upon the amount of ferro-magnesium minerals present. The greater their amount, the greater the amount of MgO and CaO in the rock. On the whole, the amount of CaO and MgO is very small. This is in accordance with the small amounts of ferro-magnesium minerals present in the rock. From the chemical analysis it is clear that the separation to be carried out is chiefly between quartz and magnetite which are easily separable by means of magnetic separators. It is likely that a part of the ferro-magnesium minerals might go with the magnetite, but as their amount is not large, it will not disturb the work.

As to transport, the area being situated near the railway station, the cost of transportation of the ore to Veerapandy at the factory will be very little. It will be possible to deliver the ore to the factory at about 10 or 12 annas per ton and as the ore contains about 50 per cent of magnetite, the amount of the ore required to produce 1 ton of magnetite will be 2 tons and the cost of two tons will be 1½ rupees. As to the cost of crushing, from the enquiries made from different firms supplying crushing machinery, the material will have to be crushed to a size of 1/10 of an inch before being sent to the magnetic separator for the separation of magnetite from silica. All the firms are of opinion that it is quite easy to carry out this separation by a magnetic separator. The cost of crushing as worked out by Krupps will be 4 annas per ton. The separation by the ordinary magnet in the laboratory of the University represented no difficulty. The University will shortly have commercial-scale crushing and electro-magnetic separation plants from America with the aid of which large-scale experiments will be carried out. If the cost of separation and crushing is assumed to be 4 annas per ton, the cost per ton of magnetite will come to 8 annas. Even assuming 8 annas to be the cost of separation, which is the highest figure, the cost of crushing and separation per ton of magnetite will come to Re. 1 per ton. Thus the total cost of mining, transport and electro-magnetic separation per ton of magnetite will range from Rs. 2 to Rs. 2–8–0.

[13] G.O. Ms. No. 2872, Development, dated 25th November 1939.

These rates compare favourably with the rates prevailing at Tata's Iron and Steel Works at Jamshedpur and at the Indian Iron and Steel Works at Burnpur. In fact, calculations show "that the cost of the pure magnetite at Veerapandy will be slightly less than that of the ore at Tatanagar and much lower than that at Burnpur."

The other raw materials (besides magnetite) required for the electro-smelting industry are limestone, charcoal, electric current, electrodes and refractory materials. Besides these, maganese, chromite and wolfram will aso be required for making steel alloys which are in so much demand these days and which have not been manufactured till now (1939) in this country. Limestone occurs in abundance near Sankaridrug, which is only 18 miles by rail from Veerapandy. It is pure calcite and, as it occurs on the flat ground, it can be quarried easily. The cost of transporting it to Veerapandy will be about Rs. 2-8-0 per ton which is much less than the cost of transport of limestone to Tatanagar and Burnpur. The use of charcoal in this electro-smelting industry is for reduction and not for producing heat. The amount of charcoal required will be 25 per cent of the weight of the steel produced. Assuming 100 tons of steel production capacity per day, for 200 days per year, the total requirements of charcoal will amount to 5,000 tons per year. This supply may be obtained from the Western Ghats. In case charcoal is not available, coke will have to be imported from outside for the reduction. The amount of coke required will be about 6,000 to 7,500 tons a year, and this can be obtained from the Bihar coal-fields. The cost of this coke will amount to Rs. 20 per ton at Veerapandy as against Rs. 12 at Tatanagar.

Electrical energy required for making alloy steels will be about 3,000 to 4,000 units per ton, this being quite sufficient to produce any kind of alloy steel. The requirements of power for producing 100 tons of steel per day will be about 15,000 Kilowatt hours. If this amount is available for 200 days, the total amount of steel produced will be 20,000 tons a year. If this current is given at Rs. 40 per Kilowatt year, the rate works out to about one pie per unit, and assuming an average consumption of 3,500 units per ton of steel produced, the cost of this amount of current will be Rs. 18 (i.e., 3,500 units). In the ordinary process of steel manufacture, the amount of coal consumed per ton of steel may be 1·5 tons. If out of this is deducted 0·25 ton required for reduction, the actual amount of coal comes to Rs. 10 ton Rs. 11 while the electrical energy sufficient for the same purpose will be costing Rs. 18. The cost of electrical energy will thus be about Rs. 7 more than the cost of coal at Tatanagar. But

electrical energy can produce better quality pig iron and different alloys of steel better than ordinary steel. So, the difference in quality of iron and steel produced is more than enough to compensate for the difference of Rs. 7 between electrical energy and coal. Moreover, this difference is much less than the cost of transport of iron and steel to Madras. So, from the point of view of cost of electricity required to produce alloy steel, Salem comes to be quite favourably situated, provided current is available at the rate of Rs. 40 per Kilowatt year, 15,000 Kilowatt hours being sufficient to manufacture 100 tons of steel per day.

Refractories also play an important part in steel manufacture as the furnance has to be lined with magnetite bricks. A very high quality of magnetite occurs at Salem only a few miles away from the Kanjamalai ore deposit, which is supplying the need of every part of the world. Tatas are getting their supplies of magnetite from Mysore which is at a distance of more than 1,000 miles. So the situation as regards refractories is quite favourable in Salem. Electrodes, however, will have to be imported from abroad. The consumption of electrodes per ton of steel is 17 lb.

There is thus a very large amount of magnetite ore in Kanjamalai enough to satisfy the need of a 100-ton steel plant for centuries. This ore can be easily crushed and treated by the electro-magnetic separator to produce pure magnetite. The process is quite simple and plants for this purpose are available. The cost of the magnetite at the works will be slightly lower than the cost of iron ores at Tatanagar. It should be seen whether powdered magnetite cannot be briquetted. If about 15,000 kilowatt hour energy is available at one pie per unit, it can successfully compete with coal at Tatanagar, the price of alloy steel manufactured being much higher than ordinary steel. The question of charcoal requires detailed investigation ; 5,000 tons of it will be required in a year. The average size of the furnace used in Sweden produces ten to twenty thousand tons per year or about 50 to 60 tons per day. Salem will require two such furnaces each producing about 60 tons of steel per day. Someone, however, should be deputed to Sweden to collect all the data of the industry.

9. In his second report,[14] Dr. Dubey elaborated some of these points and furnished information on some more points. What he said can be summarized as follows :—

Besides the Kanjamalai beds, there are other iron ore beds in Salem. All these beds should be studied in detail.

[14] G.O. Ms. No. 2872, Development, dated 25th November 1939.

Further experiments have been carried out to concentrate magnetite by the electro-magnetic separator on a semi-commercial scale. They have shown that there is no difficulty in concentrating the ore. After powdering the rock and passing it through the separator almost pure magnetite is obtained, the concentration of magnetite being easily carried out up to 90 per cent. The cost of separation is negligible and in any case will not be more than 4 annas per ton. There is very little consumption of power, the chief expense being depreciation of the plant and interest charges. There is machinery available for crushing the ore. The total cost of crushing and separation will not be more than 8 annas to one rupee per ton. But a suitable plant should be selected capable of treating about 300 tons of ore per day so that about 150 tons of pure magnetite may be obtained to yield about 100 tons of steel per day. Enquiries made from Norway have shown that it is possible to manufacture electric steel on an economic basis at Salem, i.e., at a cost something similar to that in Sweden and Norway. Besides the raw materials previously mentioned, phosphorus is necessary and this can be supplied in the form of mineral apatite which is known to occur in Tiruchirappalli district.

The investigations made have amply demonstrated the possibility of manufacture of electric steel or any kind of other alloy steel on a commercial basis, provided that 12,500 K.W.H. is available at about Rs. 40 per K.W.H. The estimated cost of the whole plant will not exceed Rs. 25,00,000 and the amount of electric steel produced will be about 20 to 25 thousand tons a year with a margin of profit of about Rs. 30 a ton.

It is, therefore, recommended (1) that the other ore deposits in Salem should be investigated and the site of the works fixed; (2) that the apatite deposits of Tiruchirappalli should be examined; (3) that magnetite ore about 1 ton should be sent to each of the manufacturers of electromagnetic separation plant and a suitable plant should be selected; and (4) that the concentrated ore should be sent to the manufacturing firms at Norway and Sweden to carry out actual manufacture before supplying the plant. All these investigations should be carried out by the Government, the expense of which may come to Rs. 7,500 or Rs. 10,000.

The gases produced in electro-smelting can be utilized for the manufacture of hydrogen for synthetic ammonia and so, if a synthetic ammonia plant is nearby, it should be possible to manufacture a good deal of hydrogen from these gases.

These views and recommendations of Dr. Dubey were strongly supported by Mr. L. B. Green, the then Director of

Industries. The Director, who entered into some details offered his remarks thus.[15]

As stated by Dr. Dubey, there is an abundance of iron ore not only in Kanjamalai, but also in other places in the Salem district. There are thus the Godumalai group, the Singipatty group, the Kollimalai-Talamalai group and the Tirthamalai group. Before deciding on the site of the proposed steel works, it would be advisable, as suggested by Dr. Dubey, to study the occurrence of the ore in the above mentioned areas so as to ensure the selection of the most advantageous site.

The iron ore of Kanjamalai, as observed by Dr. Dubey, is composed of a mixture of silica and magnetite in equal amounts. Small-scale experiments carried out at the Benares Hindu University have shown that no special difficulty need be apprehended in concentrating the ore and that, after powdering the rock and passing it through the separator, almost pure magnetite is obtained, it being possible to carry the concentration of magnetite up to 90 per cent. The experiments also seem to show that there should be no difficulty in concentrating the ore to the required degree of purity. Moreover, the cost of concentration is so low that the actual composition of the ore does not seem to be a matter of vital importance. It is true that the ore contains little calcium but a larger amount of calcite (limestone) is available within a short distance at Sankaridrug and hence, any required percentage of calcium can be mixed with the ore at the time of smelting. The question of electrical energy presents no special difficulty as the Chief Engineer for Electricity has stated that the Government could offer to supply 12,500 K.W. at Mettur at Rs. 40 per K.W. of demand per year of eight months. This amount of power would be sufficient for a plant of a capacity of 100 tons of steel per day. The question of charcoal supply, however, presents some difficulty. About 5,000 to 6,000 tons of charcoal per year would be required. The Forest Department could arrange to supply the quantity required but only at a price as high as Rs. 28 per ton. The scheme would still be practicable if coke had to be imported from outside the State, but it is likely to be costly. In Sweden, charcoal is invariably used for the production of the higher grades of steel for export, coke being used only for producing pig iron intended as raw material for ordinary steel. It would, therefore, be preferable to use charcoal if possible.

10. In regard to the production of pig iron followed by its conversion into steel and the manufacture of finished steel, it

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[15] G.O. Ms. No. 2872, Development, dated 25th November 1939.

will be seen from the letter[16] of Messrs. Stora Kopperbergs Aktiebolag Momnarfvets Jernverk, Domnavert, to Dr. Dubey that they advise that pig iron should first be manufactured and then refixed into steel in a Thomas Converter, provided there is a sufficient quantity of phosphorus in the ore or raw phosphorus could be made available at a reasonable price. If not, they state that pig iron would have to be manufactured in electric furnaces and then selected with steel scrap either in an electric steel furnace or in an Open Hearth Siemens-Martin furnace They consider that, on the basis of the prices of raw materials at Salem, it should be possible to manufacture steel on an economic basis in that area. Det Norske Aktieselakh, Oslo, in their correspondence[17] with Dr. Dubey considers that the proposal to manufacture pig iron and thereafter refine it in a Thomas Converter followed by electric steel processing would be the right one to adopt and would allow of a very economic conversion of pig iron into steel. They state that the cost of the ore, lime and power, are very reasonable and below the corresponding prices in Norway, except that power in that country is a little cheaper. For a smelting capacity of 110 tons of pig iron per day, they recommend two medium size furnaces each of 6,000 K.W. power input such as have been built by them and are in operation in Finland, Sweden, Norway and Italy for the production of high grade pig iron steel. The complete cost of crushing, concentrating and separating plant, furnace and steel-making plant, is estimated by Dr. Dubey at Rs. 20 to Rs. 25 lakhs. In their letter [18] Messrs. Det Norske Aktieselakab for Elecktrokemisk Industry have worked out the cost of manufacture of finished steels on the basis of the prices of raw materials supplied by Dr. Dubey and from the cost data given it would appear that the cost of pig iron would amount to about Rs. 40 per ton and the cost of best manganese steel to Rs. 60 per ton, against a ruling price of Rs. 120 per ton for such steel. If these figures of cost are realized in practice, even at a selling price of Rs. 80 per ton and allowing for the higher cost of charcoal and coke, a substantial profit would be realized. For, some high quality alloy steels are at present realising as much as Rs. 200—Rs. 250 per ton. Moreover, it should be profitable to manufacture even ordinary steel, if a market cannot be found for alloy steels.

The gases produced in the process of electro-smelting can be utilized for the production of hydrogen employed in the manufacture of synthetic ammonia, and, as Dr. Dubey says, it should be possible to produce an appreciable quantity of

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[16] and [17] G.O. Ms. No. 2872, Development, dated 25th November 1939.

[18] Idem.

hydrogen for this purpose from the furnace gases. It is, not, however, certain whether sufficient power can be provided at Mettur at Rs. 40 per K.W. of demand per year both for the manufacture of steel and the production of ammonium sulphate.

Dr. Dubey is anxious to proceed to Sweden and Norway in order to complete the examination and investigations. This would involve an expenditure of Rs. 10,000. The Det Norske Aktieselakab Electrokemisk state that it would greatly assist the development of the project, if Dr. Dubey visited Norway. In view of the importance of the question the expenditure involved is justifiable. If, however, the Government consider that the completion of the investigation is better left to a commercial corporation, the information collected may be furnished either to the Tata Iron and Steel Company or to the Indian Iron and Steel Company.

11. But this advice given by the Director of Industries failed to bear any fruit. The Government began to entertain doubts as to the success of the industry. This is what they said.[19] "They observe that while the Director of Geological Survey of India holds that the cost of crushing and magnetic separation of such low grade material as Kanjamalai iron ores would be so high that it would be a waste of time and money to investigate further and that the Travancore Minerals Company doubt whether magnetic separation would lead to successful enrichment, Dr. Dubey considers as a result of the small scale experiments carried out with the electro-magnetic separator at the Benares Hindu University that there should be no difficulty in concentrating the ore to the required degree of purity. Dr. Dubey can be asked to give full details of his experiments. If Dr. Dubey can convince them that his conclusions are based on correct and indisputable data, the question of sending a ton of magnetite ore to manufacturers of electro-magnetic separators in Norway and Sweden and the concentrated ore to the manufacturing firms and of ultimately selecting a suitable plant will next arise for consideration. Dr. Dubey has estimated the expenditure at Rs. 10,000, but he must be asked to give details.

12. Thereupon the Director of Industries consulted Dr. Dubey and again pressed the matter. He said that from Dr. Dubey's letter to him, it is clear that the average of the 15 analysis conducted by him shows that the mean content of magnetite (FeO) in the ore is about 50 per cent and that the average Fe content on the basis of 50 per cent magnetite comes to about 36 per cent. He stated that he agreed with

[19] G.O. Ms. No. 2872, Development, dated 25th November 1939.

Dr. Dubey that the figures were based on the actual analysis of the specimens selected by him on the spot and that they should be regarded "as more reliable than the estimated value of the Geological Survey of India". He also stated that Dr. Dubey considers that the chemical analysis made at the Benares Hindu University do not indicate the presence of much sulphur and phosphorus and this seemed to confirm the view of the earlier investigators. And he continued: "I have never been quite clear as to the basis for the more recent opinion of the Geological Survey of India that the ore is too low in iron and too high in sulphur and phosphorus to be suitable for commercial exploitation and I am not prepared to accept this view . . . I consider Dr. Dubey correct in his estimation." Finally he pointed out that Dr. Dubey's estimate of Rs. 10,000 for completing the investigation was only an estimate and nothing more. The Chief Conservator of Forests at the same time reported that it might be possible for the Forest Department to deliver the limited supply of charcoal at Mettur at a cost of somewhat between Rs. 15 and Rs. 20 per ton. But the fates were against any proposal like this at that time. For, by then the Second World War had come, and with it the economy campaign in public expenditure. It was also the time when the First Congress Ministry was about to lay down office. The proposal for pursuing the question of starting the iron and steel industry was therefore dropped in 1939.[20]

13. It was, however, revived again in 1941. As the War rolled on, the Adviser Government realized the need for exploiting the mineral resources of our State and obtained the services first of Sri N. K. N. Aiyengar and then of Dr. M. S. Krishnan, both officers of the Geological Survey of India, to investigate the Salem-Tiruchirappalli ore deposits. About the same time, the Chief Conservator of Forests reported that about 1,200 tons of charcoal could be produced annually and delivered at Mettur at Rs. 19 per ton, and that, if more supply were needed. casurina plantations could be raised near the scene of operations.[21]

14. We have already seen in Chapter II what Dr. M. S. Krishnan and Sri N. K. N. Aiyengar have said about the ores. In essence, it was this[22] that the ores are available in abundance—over 304,650,000 million tons—but they should be regarded as low grade, their iron content being about 35-40 per cent and the silica content about 50 per cent. They

[20] G.O. Ms. No. 2872, Development, dated 25th November 1939.

[21] G.O. No. 1781, Development, dated 1st October 1941.

[22] Iron-ore deposits of parts of Salem and Trichinopoly districts—G.O. No. 4832, Development, dated 11th November 1944.

have, however, not stopped with this; they have offered the following views in regard to the utilization of the ores.

15. Lack of fuel is the main difficulty. Coal is not found in South India, and though there are coal deposits in Hyderabad State (part of it now in Andhra Pradesh), none of the coals is known to be suitable for making hard (metallurgical) coke. Coke or coal has therefore to be imported from Bengal or Bihar by sea or rail. This will prove costly. Alternative ways of smelting the ores by which the dependence on coal can be cut down to the minimum have therefore to be examined. These are: (1) smelting in the blast furnace using charcoal fuel; (2) smelting in the electric furnace (using a small quantity of charcoal for reduction only and not for generation of heat); and (3) other processes such as the Stuerzelberg process.

First, as to the mining of the ores, since almost all the bodies occur at some height above the ground level, open-cast quarrying can be adopted. The general steepness of the beds will make the adoption of metal mining methods necessary. Where the deposits are at a height and contain large quantities, it may be feasible to instal wire ropes for haulage of the ore to the plains.

Secondly, as to concentration, all the ores will have to be crushed and concentrated in order to eliminate the impurities such as quartz and amphibole. The information available so far shows that most of the ores will have to be crushed to pass 10 mesh (per linear inch) for effecting a good separation. In some cases, the ore may have to be crushed much finer. As the fineness to which crushing must be done will depend upon the texture of the ore, it can be judged only after gaining some experience in determining the optimum grain size of different types for the purpose of concentration. Again, since the bulk of the ore is magnetite, electro-magnetic separation should be the most satisfactory method of concentration. The small proportion of hematite associated with the magnetite will be drawn up with the latter. If the proportion of hematite is appreciable, it would be useful to employ also tabling or wet washing. The best combination of methods will have to be worked out for the different types of ores. There seems to be little doubt that the ordinary average ore containing 35–42 per cent iron can be improved in grade to one with about 60 per cent iron. The ore can then be briquetted or sintered, if necessary, before smelting.

Thirdly, as to smelting three methods have to be considered: (1) coke-blast furnace, (2) charcoal blast furnace and (3) electric smelting. The non-availability of coal in South

India, will make the manufacture of iron in the ordinary coke blast furnace an expensive process. The use of coke will enable the operations to be conducted in units larger than those possible with charcoal fuel or electrical energy. But, as every ton of iron produced will require nearly 1 ton of coke for smelting, the cost of the raw materials will become high and will prevent the manufactured products from competing effectively with similar products made at more favourable localities. It is possible to use charcoal, instead of coke, for smelting. The charcoal consumption per ton of pig iron produced is about 16 to 17 cwts. Smelting with charoal will be feasible as in Mysore, if a regular supply can be assured by reserving an adequate area of forests for providing the wood for conversion into charcoal. One ton of charcoal can be got from four to five tons of wood. If production of say, 100 tons of pig iron per day is contemplated, it may be necessary to make 100 tons of charcoal. This would involve the provision of $365 \times 100 \times 5 = 182{,}500$ tons of wood per year, which, on the basis of a yield of 1/3 to 1/2 ton of timber per year per acre, would require an area of between 365,000 and 547,000 acres of forest land. For steel making, of course, more charcoal will be needed, and a larger area of forest will have to be reserved. Eectrical energy can replace fuel for smelting, only a small quantity of carbon as charcoal (or coke) being needed to reduce the iron oxide to metal. The charcoal needed for reduction will be around 6 to 7 cwt. per ton of iron produced, i.e., about a third of what would be rquired for both heating and reduction.

It has been said that the production of 1 ton of pig iron would require 1/3 H.P. year (say 2,200 Kwh) the electrode and charcoal consumption being 12 lb. and 8 cwt. respectively. It has also been said that an electric furnace with a capacity of 60 tons per day (such as is used in Sweden) has a loan of 6,300 K.W. which gives an output of 3·5 tons of pig iron per K.W. year. The current consumption amounts to 2,300—2,400 K.W.H. per ton of pig iron. If every high grade ore is used, the production of iron can be increased to 70 tons per day with a saving of 150 K.W.H. per ton of iron. The carbon electrodes consumption is 10 kilograms per ton of iron. As to the relative costs of electrical energy and charcoal, it has been said that the cost of electrical energy for iron smelting should not exceed £ 4 per K.W. year. This would be equivalent to about Rs. 54 per K.W. year or 0·1 anna per K.W.H. It has also been said that, to be on a competitive basis, the cost of 1 K.W. year of power should be equal to, if not cheaper than, that of 3 tons of coke.

For economy in operation and for maintaining a well-trained and adequate technical staff, it may be necessary to plan

production on the basis of 100 tons of iron per day. If electrical energy is availble at the rate of 0·1 anna or less per unit (K.W.H.), there is every chance of the electric furnace product being able to stand competition with the coke blast furnace product in South Indian markets. It is necessary to emphasise here that the smelting operations must not stop with the making of only pig iron for sale. To be really profitable, the operations should include the conversion of pig iron into steel (ordinary or alloy steel) and steel products.

There are two other processes called the " Stuerzelberg " process and the " Krupp-Renn " process. The plant for the Stuerzelberg process consists of a mill for producing and delivering pulverised coal or charcoal into the furnace, a preheater and a rotary furnace. Preliminary roasting is done, if necessary. The mixture of ore, coal and lime (flux) is preheated by the waste gases and the pre-heated material passes into the rotary furnace where it is heated by the fuel (coal dust), the highest temperature developed being around 1,500°C. A pasty slag and sponge iron are then formed, the slag surrounding the masses of sponge-iron. The slag composition is kept highly basic for effective de-sulphurisation. The waste gases pass through a slag and ash catcher and thence through the regenerator and to the pre-heater. This, and the Krupp-Renn process which have been developed since 1934 are suitable for low grade ores like lateritoid materials, residue from roasting pyrites, etc., which cannot easily be beneficiated. It would, therefore, appear that, provided electrical energy can be made at cheap rates, electric smelting would be the most suitable for treatment of the Salem ores. The price which electro-metallurgical industries can afford to pay for electricity is around 1/12 to 1/10 anna per K.W.H. or say, round Rs. 50 per K.W. year.

As to fluxes and refractories, the auxiliary materials required for the iron and steel industry, the fluxes both limestone and dolomite, are available in the Salem district itself, as also in Tiruchirappalli and Coimbatore. Amongest the refractories fire clay, magnesite, chromite and silicious materials like quartzites and quartz schists are available with the State, and mostly within short distances of the iron ore deposits. These materials will be available to an iron and steel works in the Salem district at no higher cost than what other similar works are paying for them.

Finally, as a preliminary to the working and smelting of these ores, it will be necessary to conduct investigations on a fairly large scale on crushing, methods of concentration, sintering or briquetting and smelting in order to determine the best practice to be followed and to work out the approximate cost of the operations. These must be carried out by

specialists either in well-equipped laboratories or in works where there are facilities. With sustained effort it should not be difficult to solve the problem of smelting the ores and making them serve as the basis of an iron and steel industry in our State.

But no sustained effort as suggested by Dr. M. S. Krishnan and Sri N. K. Aiyengar were made for some time. Their report was merely published[23] for the information of interested parties and this was done firstly because the termination of the Second World War made any sustained effort on the part of the State unnecessary and secondly, because the attention of the British Government was then almost wholly concentrated on the transfer of power and nothing else. Since the establishment of the National Government, however, some attempts have been made to explore the possibilities of the industry again; and these will be dealt with in the next chapter.

G.O. No. 4832, Development, dated 11th November 1944.

CHAPTER V.

PRESENT POSITION OF IRON AND STEEL INDUSTRY IN MADRAS.

(SUPPLEMENT TO THE LATE DR. BALIGA'S COMPILATION ON THE PROSPECTS OF AN IRON AND STEEL INDUSTRY IN MADRAS.)

In this and last chapter, it is proposed to describe the position of the industry from 1947 onwards, i.e., since the accession of the National Government, devoting attention to the attempts made to ascertain the prospects of the industry especially in view of the discovery of lignite in Neyveli and surrounding villages in the South Arcot district. It may, however, be mentioned here that none of the attempts has emerged from the realm of experiments and in this realm, while some experts had held out promise, others had not done so. But all the same, hopes have been persistent about the bright future of the industry.

2. In 1947, the Government of Madras addressed the Government of India to the effect that although the Iron and Steel Panel set up by the Government of India for considering the possibilities of developing the iron and steel industry in India was of the opinion that except Bihar and West Bengal, there was no part in India where a major iron and steel plant could be established, the Government of Madras, in view of the existence of almost inexhaustible reserves of good grade iron ore in this State, and of the availability of all other facilities required for the industry, had decided to proceed with their plans of setting up an iron and steel plant at Salem, which decision was communicated to the Government of India followed by a memorandum later on. They also pointed out that manganese for production of ferro-manganese could be made available from the Sandur area in the Bellary district (now in Mysore State), that coke could be brought from Singareni (now in Andhra Pradesh) or through Marmagoa Port (Portuguese Colony), that electric power could be supplied either from the Jog falls or from the Tungabhadra dam (both in Mysore now) and that from a strategic point of view the location of the unit at Salem was highly desirable. They urged the Government of India to locate in the Madras State one of the two steel plants (each of 500,000 tons ingot capacity and each capable of being doubled) which were proposed to be set up in the country and for which technical advice from the United States of America or United Kingdom was being sought.[1] But the Government

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[1] Letter No. 3531, P. & D. III|47-8, Development, dated 5th August 1948, to Government of India—*vide* Letter Ms. No. 2809, Industries, Labour and Co-operation, dated 12th October 1954.

of India decided to set up one plant in the Central Provinces (now in Madhya Pradesh) and the other in the Orissa State.[2]

3. In 1948, two American firms, namely, Messrs. Arthur G. McKee and Company[3] and Messrs. Koppers Company, Inc., Pittsburg, U.S.A.,[4] both steel consultants of the Government of India were consulted. In answer to their questionnaire, they were informed, among other things, that electric lines ran from Mettur to the centre of the iron ore area in Salem, that power generated at Mettur and required for the proposed industry could not however be met in full from the existing sources, that new schemes would have to be worked out and that power could be partly supplied when the Periyar, Sileru and Mekadatu schemes were completed. They were also informed that the power produced then was 40,000 K.W. and 20,000 K.W. seasonal supply and that the cost per K.W.H. was 9 pies (5 naye paise) per unit. They were likewise informed that the most suitable site for setting up the industry was situated between the Cauvery railway station and Pallipalayam on the broad gauge line of the Southern Railway, that there was there adequate water supply from the Cauvery and that at a short distance from these, fluxes, like dolomite and limestone and refractories like magnesite were available[5] But they both came to the conclusion that there was little prospect of exploiting the ore in Salem as it contained only about 35 per cent of iron and as it had to be magnetically concentrated " by an expensive process before reduction ". They refused to visit Salem, though they were pressed to do so.[6]

4. Shortly afterwards, Sri H. K. Ghose, Consulting Mining Engineer, Geologist and Officer-in-charge of Lignite Investigation, Neyveli, submitted a note to the Government on the manufacture of pig iron from the Salem ores by the use of South Arcot lignite.[7] What he said in essence was that Germany, like South India, is poor in her coal and iron resources. It has also like South India iron ore deposits which have low iron content. And yet, between the two World wars, Germany has developed her ore, Lorrain

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[2] Letter No. I (5)-10 (17)|49, dated 31st January 1950, from the late Ministry of Industry and Supply—*vide* Letter Ms. No. 2809, Industries, Labour and Co-operation, dated 12th October 1954.

[3] G.O. Ms. No. 635, Development, dated 16th February 1950.
G.O. Ms. No. 636, Development, dated 16th February 1950.

[4] G.O. Ms. Nos. 635 and 636, Development, dated 16th February 1950.

[5] G.O. Ms. No. 636, Development, dated 16th February 1950.

[6] G.O. Ms. No. 1140, Development, dated 20th March 1950.

Minette, and shown that good quality pig iron can be obtained from ores with high silica content. Lorrain Minette contains only 35 per cent of iron whereas an average sample of Salem ore contains over 40 per cent of iron. The silica content of the German ore is much higher than that of the Salem ore.

Experiments have proved that South Arcot lignite, though of a non-coking variety, has good reactive properties which makes it a suitable shaped metallurgical coke. It is also stated that suitable shaped metallurgical coke can be manufactured from lignite. If so, there is no reason why metallurgical carbonisation methods cannot be employed to the smelting of Salem iron ores by means of South Arcot lignite.

The lignite deposits of South Arcot and the iron ore deposits of Salem-Tiruchirappalli region hold out possibilities for the industrial development and economic prosperity of India as a whole and of South India, in particular It is therefore essential that the lignite deposits should be developed as early as possible and the iron deposits should be surveyed immediately in detail. Samples of the South Arcot lignite should be sent to different countries abroad working on lignite or brown coal for experimenting on the following lines to know (1) its usability in industrial boilers in its raw state; (2) its usability in a pulverised form for mill-finings; (3) its usability in pulverised form in compressed air-gas turbines in place of oil; (4) the bye-products recoverable from it; (5) its usability in the manufacture of shaped lignite coke suitable for metallurgical purposes; and (6) its usability for metallurgical coking in a briquetted form with crushed (*a*) unbeneficiated and (*b*) beneficiated Salem ore. A thorough survey of Salem-Tiruchirappalli iron ore deposits by (*a*) mapping, (*b*) boring and (*c*) pitting and trenching should be undertaken without delay for the proper appreciation of its value. Samples of the ore should be sent to various countries where extensive research has been carried out on the commercial development of low grade iron ores and especially to Germany where they have developed the metallurgical upgrading of low grade iron ore by the two-step metallurgical carbonisation process. Experiments should also be carried out locally for (*a*) concentration of the ore by the dry and wet gravity separation process, (*b*) smelting in experimental electric furnaces and (*c*) smelting in experimental blast furnaces. A few trained metallurgists may be sent abroad to learn the working of the different process.[8]

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[8] G.O. Ms. No. 1140, Development, dated 20th March 1950.

5. Messrs. Electrokemisk, A/S, Oslo, Norway, who conducted tests on Salem ore and South Arcot lignite reported (1951) as follows :—[*]

Samples of 10 lbs. of lignite have been tested in the laboratory. The lignite seems to be well suited, for use in the electric pig iron furnace without briquetting and the only preparation needed is carbonising. Information regarding carbonising can be obtained from the Lurgi Apparatebau—Gessellschaft, Frankfurt am Main, Germany. Fifteen lbs. of ore I (Sandur) and ore II (Salem) were received from the Government early in 1950. The analysis of these are given below :—

	Ore No. I percentage.	Ore No. II percentage.
Fe	69·7	69·5
SiO_2	0·35	1·65
Al_2O_3	1·65	1·67
CaO	trace	trace
MgO	0·22	0·33
MnO	0·13	0·13
S	0·03	0·02
P	0·01	0·015

These ores are extremely rich and have excellent characteristics for production of iron and steel. The sulphur and phosphorous contents are low. Smelted in an electric furnace a high grade pig iron can be produced. The sulphur content will be about 0·030—0·015, possibly less. The phosphorous content will be about 0·015—0·025 per cent depending upon P content of the other raw materials. This pig iron will be an excellent raw material for high quality steel (alloy steel). It is also well suited for foundry purposes and can also be converted into malleable castings and plain carbon steels. Standard grades of commercial steel can be produced from the acid Bessemer process. Judged from the small supplies received, these ores will not need any other pre-treatment than crushing to below 3 inches for smelting in the Tysland-Hole Furnace.

6. But the samples of the Salem ores received towards the end of 1950, are, however, not good. Ore A, B, C of the samples were ground and chemical analyses were made. They show as follows :—

	A Percentage	B Percentage	C Percentage
Increas of weighte	0 80	1 10	1 10
Fe	35·0	37·7	34 8
SiO_2	46·4	44 9	46 2
Al_2O_3	0·1	0·1	0·1

[*] Report, dated January 1951, on tests conducted with Salem iron ore and South Arcot lignite—*vide* G.O. Ms. No. 3676, Development, dated 21st August 1952.

	A Percentage.	B Percentage.	C Percentage.
CaO	0·85	0·95	1.15
MgO	1·60	2·00	2·15
MnO	0·05	0·05	0·04
S	0·04	0·04	0·04
P	0·14	0·14	0·13

7. These ores are low grade qualities of a ferruginous-quartzite types. They might, however, be smelted in the electric furnace as mined, but this procedure would be very uneconomical and concentration is definitely recommended. The ore lends itself well to magnetic concentration. Feb recovery is about 91 per cent for A and B and about 86 per cent for C which may be considered satisfactory. Contents of A, B and C can be blended with ore I and II and the ore-mix kept within the specification range of Bessemer grade. The final conclusion is that lignite and iron ores are all, after pre-treatment, high grade raw materials for production of pig iron in the Tysland-Hole Furnace.

8. The United States Bureau of Mines about the same time tested a sample of the Salem ore and reported [10] thus: Individual representative portions of the samples were crushed to pass 10, 20, 35 and 65 mesh screens and treated separately in a Davis tube separator. The ore assays approximately 37 per cent iron and is too low grade for efficient smelting in blast furnace without beneficiation. Since the iron content is magnetite, the simplest method of concentration would be magnetic separation after grinding to a size that will give a desired grade of concentrate. Grinding however to minus 10 mesh is not sufficient to yield concentrates assaying over 50 per cent of iron. At minus 20 mesh concentrates assaying over 60 per cent are produced. Grinding to minus 35 or 65 mesh will yield higher grade concentrates but the difficulties involved in agglomertating the finer concentration for blast furnace use would make it perhaps more economical to produce minus 20 mesh concentrate.

9. Meanwhile, the Technical Co-operative Administration, United States of America. tendered advice to the Government of India for setting up a new steel plant in a place other than Madras, without, however, examining the Salem ore deposits of considering the possibilities of using South Arcot lignite for smelting them. [11] When Government of Madras

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[10] Report, dated 29th February 1952, on magnetic separation tests on a sample of Salem iron ore—G.O. Ms. No. 983, Development, dated 3rd March 1953.

[11] Letter, dated 27th May 1953, from Mr. C. H. Willson, U.S. Director of Technical Co-operation Administration for India and Letter No. 18 (5)-Tech.|52-S, dated 24th July 1953, from the Government of India, Ministry of Finance (Department of Economic Affairs)—*vide* Madras Government Letter Ms. No. 87, Industries, Labour and Co-operation, dated 12th January 1954.

came to know this early in 1954, they wrote to the Government of India stressing the claims of Madras.[12]

10. They said,[13] they are fully aware that the question of establishing a new steel plant is under the consideration of the Government of India and that technical advice is in favour of location of the new plant in a place other than Madras. But the Madras Government have not agreed to this position and have been impressing upon the Government of India from time to time on the feasibility of starting an iron and steel industry in South India. They have always held that it is possible to start an iron and steel industry in this State utilising the lignite found in South Arcot and that an expert should be invited to advise on the possibility of utilising the iron ores with lignite for the iron and steel industry in South India. They have, therefore, requested the Ministry of Commerce and Industry to obtain the services of an expert for the purpose under the Point Four Programme. They have also sent representative samples of lignite and iron ores to Messrs. Lurgi and Company, Germany, and the United States Bureau of Mines for plant scale trials and for reporting on the economic feasibility of starting an iron and steel industry in South India. Action is also being taken to conduct a detailed survey of the iron ore bearing regions in the South. The investigation of economic mining of lignite is proceeding apace. It would appear that lignite could be produced at low cast. This places Madras in a very advantageous position in regard to the establishment of an iron and steel plant. In these circumstances, they consider that the claim for the development of this industry in South India should again be pressed and that the investigation into the iron and steel industry proposed by the Technical Co-operation Administration should be commenced in Madras without delay.

11. But the Government of India opposed this move. They said that there was no possibility, in view of the overall economics of the project, of setting up the new steel plant in Madras and that the request from Madras could be kept in mind if and when it was desired to have another plant. They therefore asked our Government to drop the proposal so that

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[12] Letter No. 69635 P. & D. III|53-2, dated 19th August 1953, to the Government of India—*vide* Letter Ms. No. 87, Industries, Labour and Co-operation, dated 12th January 1954.

[13] Letter No. 69635. P. & D. III|53-2, Development, dated 19th August 1953 to the Government of India—Vide letter Ms. No. 87, Industries, Labour and Co-operation, dated 12th January 1954.

the Point Four Authorities might be informed that the services of their expert were not required for Madras.[14]

Upon this, our Government decided not to press the matter "for the present", but wrote that they might however renew the proposal as soon as they were satisfied about the economics of lignite mining.[15]

12. In October 1954, the Government of Madras addressed the Planning Commission to arrange for an expert study, if necessary, with the assistance of foreign specialists to design and construct an iron and steel plant in this State and, in the meantime, to include the scheme as a centrally-sponsored one in the Second Five-Year Plan. They pointed out that, of the raw materials required for the industry, namely, magnetite ore, limestone, coal and cheap electrical energy, the first two were available in this State as natural deposits and carbonised lignite and electrical energy expected to be produced from the lignite project would supply the remaining two requirements.[16] The Planning Commission, however, replied that the subject could be taken up for consideration only after the possibilities of lignite development had been thoroughly studied on the basis of the expert investigation then in progress, that a good deal of preliminary work had to be done before large scale mining of lignite in South Arcot could be started, that it would be several years before carbonised lignite and electrical energy would become available from the project and that in the circumstances, it was premature to take up the detailed investigation of a steel project in Madras and that the appropriate time to investigate would be after the lignite scheme was well under way.[17]

13. Shortly afterwards (early in 1955) our Government received the reports of the United States Bureau of Mines[18], and Messrs. Lurgi Gessellschaft Fur Warmetechnik m.b.h.,

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14 Letter No. 18(5)-Tech.|52-S, dated 13th November 1953 from the Government of India, Ministry of Finance, (Economic Affairs) to Madras Government—Letter Ms. No. 87, Industries, Labour and Co-operation, dated 12th January 1954.

15 Letter Ms. No. 87, Industries, Labour and Co-operation, dated 12th January 1954.

16 Letter Ms. No. 2809, Industries, Labour and Co-operation, dated 12th October 1954, to the Planning Commission.

17 Letters Nos. P.C.(iii)|4|12|54, dated 30th October 1954 and 5th January 1955, from the Planning Commission—Vide letter No. Ms. 2809, Industries, Labour and Co-operation, dated 12th October 1954.

18 Report, dated August 1954 on beneficiation of iron ore from Salem and tests on reduction of concentrate with South Arcot lignite and char—G.O. Ms. No. 1685, Industries, Labour and Co-operation, dated 9th May 1955.

Frankfurt, am Main, Germany to whom they had sent the Salem iron ores and South Arcot lignite for tests.

14. The United States Bureau of Mines carried out the beneficiation tests of the Salem iron ores and the tests on reduction of the concentrate with South Arcot lignite and char. It reported thus :[20].

A petrographic examination was made on a 5 lb. sample of the ore. The ore was found to be composed chiefly of magnetite and quartz with minor amounts of accessory minerals. Microscopic examination of sieve size fraction indicated that liberation between the quartz and magnetite was greater than 90 per cent complete in the 48-mesh size range. Table 1 given below shows the data resulting from this examination :—

TABLE 1.

Percentage of Magnetite liberation determined by Microscopie Examined on.

Sieve size.	Weight, per cent.	Per cent liberation.
— 6 + 10	33·3	2
— 20 + 10	21·9	10
— 20 + 35	15·0	75
— 35 + 65	11·9	99
— 65 + 100 ..	5·4	99
— 100 + 150 ..	3·5	99
— 150 + 200 ..	2·7	99
— 200	6·3	99

On the basis of this information all beneficiation tests were made on ore ground to pass a 48 mesh sieve. Since the principal mineral present was magnetite, beneficiation of the ore by magnetic separation was readily accomplished by using either wet or dry type separators. The maximum beneficiation was received by using a Davis tube wet magnetic separator. The concentrate from a typical Davis tube test on a minus-48-mesh sample assayed 66·7 per cent Fe, 5·3 per cent

[19] Report on the process of magnetic separation, etc. with South Arcot lignite and Salem iron ore—G.O. Ms. No. 1685, Industries. Labour and Co-operation, dated 9th May 1955.

[20] Report dated August 1954 on beneficiation tests of iron ore from Salem and tests on reduction of concentrate with South Arcot lignite and char—G.O. Ms. No. 1685, Indistries, Labour and Co-operation, dated 9th May 1955.

insoluble and contained 95·2 per cent of the total iron in the ore. Table 2 shows the data obtained from this test :—

TABLE 2.

Results obtained by Davis tube wet magnetic separation.

Product.*	Weight, per cent.	Assay, per cent.		Distribution, per cent.	
		Fe.	Insol.	Fe.	Insol.
Magnetic ..	56·0	66 7	5·3	95·2	6·8
Non-magnetic.	44·0	4·3	92·7	4·8	93 2
Total ..	100·0	39·2	43·8	100·0	100·0
Head ..	38·7	38·7	44·2	..	..

* Ore ground through 48–Mesh. Magnet operated at 110 volts, d.c.

15. Similar results were obtained at the College Park station. Data from this report also showed that Davis tube magnetic concentrates made on samples ground through 10–, 20– , 35– , and 65– mesh sieves respectively assayed from 49 0 per cent Fe at a –10 mesh grind to 67·7 per cent Fe at the 65– mesh grind. Iron recoveries for these concentrates were respectively 97·7 and 93·6 per cent. These data are shown in Table 3 and they demonstrate that lower grade concentrates may be obtained at coarser grinds while iron recovery values are still maintained relatively high.

TABLE 3.

Rusults obtained by Davis tube magnetic seperation tests made on ore crushed through 10—,20—,35— and 65— mesh *

Size mesh	Product.	Weight per cent.	Analysis, per cent. Fe	TiO_2	P	Per cent of total Fe
—10	Magnetic	72·5	49·0	0·40	0·084	97·7
	Non-magnetic ..	27 5	3·1	..	..	2·3
	Total	100·0	36 4	..	..	100·0
—20	Magnetic	58·5	60·6	0·32	0·057	93 4
	Non-magnetic ..	41·5	3·2	..	..	3·6
	Total	100·0	36·8	..	..	100·0
—35	Magnetic	54·5	65·6	0·38	0 052	96 0
	Non-magnetic ..	45 5	3 3	..	..	4·0
	Total	100·0	37·3	..	..	100·0
—65	Magnetic	50·0	67·7	0·45	0·036	93·6
	Non-Magnetic ..	50 0	4·6	..	..	6·4
	Total ..	100 0	36·2	..	..	100·0

* Data taken from College Park station report of February 1952.

16. A minus-48-mesh sample of the ore was also tested in a Stearns cross-belt dry magnetic separator. Results from this test are given in Table 4. The concentrate product was obtained by clearing the non-magnetic product two times.

TABLE 4.

Concentration test results obtained by dry magnetic seperation made on a Stearns cross-belt separa or.

Ore ground through 48—mesh, Magnets operated at 0·15. a.m.p.d.c.

Product.	Weight, per cent.	Assay, per cent.		Distribution, per cent.	
		Fe.	Insol.	Fe.	Insol.
(1)	(2)	(3)	(4)	(5)	(6)
Composite concentrate.	55·9	64·7	8·2	92·6	10·6
Non-magnetic tailing.	44·1	6·5	88·8	7·4	89·4
Total ..	100·7	39 0	43 8	10[illegible]·0	100 0
Head	38·7	44·2			

17. A laboratory Carpco high-tension electrostatic unit was found to dry concentrate from a minus 48-mesh sample of the ore to a high-grade concentrate product. However, recoveries were generally lower than values obtained by magnetic separators. Results from this test are shown in Table 5. The concentrate product was obtained by cleaning the tailing four times.

TABLE 5.

Results obtained by concentrating magnetite in labratory carpco hightension electrostatic unit.

Ore ground through 48- mesh and fed to unit hot. Unit was operated at 26-37 kilovolts.

Product.	Weight, per cent.	Assay, per cent.		Distribution, per cent.	
		Fe.	Insol.	Fe.	Insol.
(1)	(2)	(3)	(4)	(5)	(6)
Concentrate ..	43·6	68·9	2·8	73·7	2·9
Tailing	56·4	19·0	71·5	26·3	97·1
Total ..	100·0	40·7	41·5	100·00	100·0
Head		38·7	44·2	...	..

18. Comparison of results from the various laboratory tests indicates that a dry treatment method could be used to satisfactorily concentrate the ore; however, metallurgical results with respect to grade of concentrate and recovery of iron were not as good as were obtained by a wet method. Should water supply be a critical factor in processing the ore, dry concentration may prove to be desirable.

19. A 500 lb. sample of coarse ore, which was not identical with the 5 lb. ore sample as it contained 35·9 per cent Fe while the 5 lb. sample contained 38·7 per cent Fe, was subjected to tests. Nevertheless, the sample responded to magnetic concentration. In order to attain a sizable quantity of concentrate for pyro-metallurgical treatment, several hundred pounds of the ore were dry ground through 50– mesh and this material was treated in a 12– inch by 5– inch Jeffrey drum-type wet magnetic separator. The crushed ore was fed to the separator at the approximate rate of 2 lb., per minute or 120 lb. per hour. Operating data and results from this test are given in Table 6. Table 7 presents seieve size analysis of the feed and the iron concentrate product. The concentrate was made with single pass through the concentrator. It will be noted from the metallurgical data presented that somewhat inferior results were obtained in this continuous operation test as compared to those obtained in smaller scale laboratory tests. Undoubtedly, improved metallurgical results would be obtained by the use of a continuous processing method wherein a cleaner circuit would improve final grade, and middling would be cycled for re-treatment. However, it was not considered necessary to do this in this preliminary study.

TABLE 6.

Data on continuous wet magnetic separation tests made with a Jeffrey 12 inch × 5 inch drum separator.

Ore ground to pass 50 mesh.

Magnets operated at 2·4 amp.

Drum speed 43 r. p. m.

Feed rate approximately 2·0 pounds per minute or 120 pounds per hour.

Product.	*Weight, per cent.*	*Assay, per cent*		*Distribution per cent.*	
		Fe.	*Insol.*	*Fe.*	*Insol.*
Concentrate	53.9	63.3	7.9	89.3	9.6
Non-magnetic	46.1	8.9	86.5	10.7	90.4
Total	100.0	38.2	44.1	100.0	100.0

	Assay, per cent.			
	Fe	*Tio2*	*P.*	*Sio2*
Head	35.9	0.00	0.15	44.9

TABLE 7.

Sieve size analysis on magnetic concentrate and ore feed used in the continuous magnetic separation test.

Sieve size, mesh.	Weight, per cent. Ore feed.	Weight, per cent. Magnetic concentrate.
−48	0·3	2·3
−48 +65	17·0	19 6
−65 +100	21·5	23·6
−100 +150	17·4	16·6
−150 + 200	13·3	11·5
−200	32·5	26·4
Total ..	100·0	100·0

20. In summation it may be stated that beneficiation of the ore is a relatively simple problem and may be accomplished by either dry magnetic separation or more efficiently, by wet magnetic separation. Essentially complete liberation of iron minerals can be obtained at 48-mesh but coarser sizes can be treated provided lower grade final concentrates are acceptable.

21. Again, the 63·3 per cent iron concentrate, as shown in Table 6, was subjected to a series of laboratory sintering tests using as fuel (1) lignite from South Arcot or (2) char from the lignite. The sintering tests were not too successful in as much as both concentrate and the reducing materials have a relatively fine grain size. Under such conditions, a high circulating load of return fines would be required to agglomerate this iron concentrate product into a good hard sinter. However, these concentrates can be agglomerated into a good hard product by pelletizing (without added binder). The product in this instance is pressed into cylindrical shaped 1- inch diameter by 1-½ inch long pellets and heat treated at a temperature of 2,200° to 2,400° F. Continuous balling processes would probably work as well.

22. In continuing the study the heat treated pellets were reduced to sponge iron with lignite and also with lignite char by placing the pellets in a graphite crucible and surrounding them with the reducing agent and then heating to 1,800°F for an hour. Thereafter, it was found that the pellets that had been reduced with either lignite or char had expanded and were quite soft and sponge-like. After reduction in this manner, the pellets are not stable and will re-oxidise. However, they may be heated above 2,200°F, in the presence of the reducing agent. When this is done, they shrink into a more compact hard form and are more resistant to oxidation.

23. Any agglomerated iron ore concentrate, which must be subsequently reduced and smelted to produce a metallic iron product, must be processed in shaft or electric furnaces. The physical nature of the lignite or a char produced from lignite precludes use of this material as fuel in a standard blast furnace. Similarly, the physical nature or form of the reduced pellets, unless they were reduced at temperatures in excess of 2,200°F, would prevent their satisfactory use in a standard blast furnace.

24. It is, however, possible that some type of a briquet might be made from the lignite products that would be suitable as blast furnace fuel, but the production of such briquet was not within the scope of the present study.

25. The general picture which is obtained from these exploratory tests using 500– to 5,000–gram samples for the production of metallic iron from magnetite concentrate and lignite, leads one to believe that the lignite should be used to produce a char and electrical energy. Both products could be used in the production of iron in electric furnaces. Char is a much better reducing agent than the raw lignite, as it has a lower volatile, and hence, higher fixed carbon content.

26. In order to simplfy the processing of the iron ore concentrate, a test was made by placing alternate layers of concentrate and char in a graphite crucible and heating the crucible to 2,700°F in an electric furnace. As the volume of the charge decreased, more concentrate and char were added. From inspection, it was seen that the reduced iron was not coalescing satisfactorily due to the unliqufied gangue contrained in the concentrate plus the ash and solid carbon in the char. A flux composed of trona, calcium oxide and silica was added. At the end of two hours a very good, quiet melt was obtained. The crucible was taken from the furnace, allowed to cool and the iron button removed. The results of a chemical analysis of the iron button are given in Table 8.

TABLE 8.

Chemical analysis of iron button.

Percentage

Fe	C	P	Ti	Mn	S.	Inse
97.1	2.21	0.03	0.0	0.0	0.01	0.10

27. These results of the experiments given by the United States Bureau of Mines were, on the whole, favourable. So also were favourable its opinion based on the results. But the opinion given by Messrs. Lurgi and Company of Germany though favourable, was not conclusive based as it was, they said, on a poor sample of the ore that was sent to them;

instead of the average sample as was promised to be sent to them. This is what they said : [21]

"The Salem ore samples forwarded for analysis have shown an Fe content of 36·63 per cent by weight and Sio content of 46·86 per cent by weight. It is not known whether these are the correct samples since, according to the results indicated from Madras, the Fe content amounted to 44·2 per cent, i.e., 47·60 per cent Fe_2O_3 and 14.04 per cent by weight Feo, and Sio_2 content to 22·25 per cent. It is noted that the idea is to beneficiate the ore by magnetic separation and then to smelt it in an electric furnace. However, it should be remembered that, according to the analysis results, the ore is not a pure magnetite. It is true that with a crushing to 0–4–0 24 mm. a good beneficiation can be achieved in the magnetic concentrate. But, the smelting waste contains a considerable amount of non-magnetic or only feebly magnetic iron oxides so that the concentrate yield will only be small with the processes intended to be adopted. Experiments have shown that briquetting of the concentrate will be possible. It may even be rolled into pellets, but this would still have to be proved. As far as is known, pellets and briquettes after preceding low-temperature carbonization can be changed to the furnace as a mixture only, but never alone. Moreover, it should be mentioned that ores are much more conveniently treated in an electric shaft furnace when being sintered. The heat required for the sintering process could be fully met by low temperature coke which would have to be processed from South Arcot lignite.

28. In any case, whether the ore is sintered or not, the Company went on to observe, the coke and power requirements for the reduction process in the electric furnace will amount to 450 Kg. of coke and 2.400 K.W. Hr. Basing on German conditions where the price per coke amounts to DM 45 per ton and that for 1 K.W. Hr. to 0·05 DM, the expenditure involved would be DM 165 per ton of pig iron. To these costs will have to be added, the costs for crushing, magnetic benefication and eventually for briquetting, pelletising or sintering costs which are not likely to be immaterial. For the above reasons, including the low yield of concentrate, the project will no longer appear economical. We are of opinion, therefore, and here we find ourselves in agreement with Messrs. Krupp, that the Renn process is most appropriate in your case. As the smallest unit of a Renn furnace acceptable from an economic

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[21] Report on the process of magnetic separation, etc. with South Arcot lignite and Salem iron ore—G.O. Ms. No. 1685, Industries, Labour and Co-operation, dated 9th May 1955.

point of view, we recommend an experimental Renn furnace with a diameter of 3 m and a length of 55 m."

29. The firm, of course, said that their opinion could not be considered as final as they did not know the exact composition of the ore as stated at the outset. Moreover, they wanted to know the exact results of the magnetic separation which might have been carried out in Madras so as to compare the method with other process. They however said that "it will be definitely possible to use the South Arcot liginte for the production of the low temperature coke required for the Renn smelting process." "This means", they went on to say, "that an iron works where the Salem iron ores would be subjected to smelting could be operated by native fuels of South Arcot."

30. Close on the receipt of these reports, Sri B. Patnaik of the Kalinga Ferro Alloy Corporation submitted[22] a scheme to the Government on the utilization of the low grade Salem ore and South Arcot lignite or other low grade coal for the production of pig iron. He said that the only economic process of producing pig iron out of the low grade iron ore abundantly available in the Salem district and out of the lignite available in the South Arcot district, is by the latest low shaft method. Till such time as the lignite is not available, some other suitable coal may be used. The iron ore will have to be treated to increase the Fe content to at least 55 per cent from the average Fe content now existing in Salem ore, at 35 per cent. Lignite will have to go through a process of drying and pre-carbonizing before it is fed into the low shaft furnace. A preliminary furnace with a capacity of producing 2 tons of pig iron per hour should be established at a suitable place, utilising Salem iron ore and South Arcot lignite. The hot gases released out of the furnace to generate an approximately 5,000 K.W. of electricity per hour should be utilized. Electricity produced by the utilization of these gases will cost below 9 pies (5 naye paise) per K.W. House, which admittedly is a reasonable cost for thermal generation. This figure is based on the presumption that raw lignite would be availble at Rs. 6 per ton and raw iron ore at Rs. 8 per ton. The estimated total over-all cost of a low shaft furnace capable of producing about 2 tons of pig iron per hour would be about Rs. 25 lakhs. Apart from this, the boiler for generating sufficient steam by utilizing the gases of the low shaft furnace, i.e., 30 tons of steam per hour at 80 atmospheric pressure, is estimated to cost about Rs. 35 lakhs. The electrical equipment to generate 5,000 K.Ws. per hour is also

[22] Letter, dated 5th March 1955 to Hon. Sri M. Bhaktavatsalam, Minister, Madras Government—G.O. Ms. No. 413, Industries, Labour and Co-operation, dated 5th February 1957.

estimated to cost about Rs. 25 lakhs. Besides this, some funds must be allocated for the development of the iron ore mines, and these may not exceed Rs. 10 lakhs.

31. All this was in 1955. In 1956, the Neyveli Lignite Corporation (Private), Limited forwarded[23] to the Government a report written by Dr. C. V. S. Ratnam, one of their experts, on the use of coal and lignite and the reduction of iron ore in low shaft furnaces in some Plants in East Germany. It is not necessary to summarise this report here as it merely contains some discussions which he had with the East German firms. But we may mention here the results of the chemical analysis of the Salem ores carried out by Dr. Ing Von Struve in East Germany at the instance of our Government.

32. Dr. Struve gave the following report.[24] The chemical analysis of the ore was as follows:

29.22	Per cent	Fe_3O_4
14.77	,,	Fe_2O_3
0.02	,,	MnO
0.72	,,	CaO
48.90	,,	SiO_2
3.83	,,	Al_2O_3
0.63	,,	MgO
0.25	,,	P_2O_5
0.43	,,	SO_3
0.03	,,	TiO_2
0.06	,,	As
..	,,	Cu
..	,,	Zu
1.66	,,	Annealing loss.

33. The ore is a magnetite-hematite ore. It is characterised by an extremely high silica content with an Fe content of only about 32 per cent. Its phosphorus content is within such limits (0·109 per cent) as to render it suitable for manufacture of steel iron. A very favourable feature is its low content of alkalis and the absence of copper and zinc. It was not possible to make smelting and dressing investigations, but from the chemical analysis it can be inferred with certainty that neither a blast furnace nor a low shaft furnace can be directly charged with it.

34. Two ways of manipulating the Salem ore might be considered. (1) Dressing of the ore by combining it with an ore which has a higher Fe content and which is less acid.

[23] Letter, dated 15th September 1956—G.O. Ms. No. 413, Industries, Labour and Co-operation, dated 5th February 1957.

[24] Letter, dated 22nd March 1957, from the Deputy Trade Representative of German Democratic Republic in India—G.O. Ms. No. 413, Industries, Labour and Co-operation, dated 5th February 1957.

The Mysore ore is said to have an iron content of 60 per cent and an SiO_2 content of 2 per cent. Mixing the two ores at the rate of 50 per cent would lead to an increase of about 32 per cent of the output. At the same time slag quantity would be reduced to about 12·00 kg. per ton of pig iron. Under these circumstances the Salem ore could even be smelted in the blast furnace. (2) Smelting of the ore after preceding concentration. Due to the magnetic qualities of the ore, a magnetic dressing seems promising at first. The intimate combination of the ores, however, causes some difficulties with regard to the separation of the magnetite from the non-magnetic compositions. One may, however, say with comparative certainty that Salem ore is well suited for the Renn process (Krupp-Renn plant). But it will be necessary to disintegrate the relatively lumpy ore. To be on the safe side, half-technical or large scale technical experiments should be made in order to finally ascertain which smelting process is the most economical with the Salem ore.

35. In 1957, the Government clarified their attitude in the matter of establishing an iron and steel plant in Salem, by issuing a Press Note.[25] In this Press Note, dated 17th June 1957, they said as follows.

36. Sometime ago, while answering an interpellation in Parliament, the Minister for Heavy Industries is reported to have stated that a licence is proposed to be granted to a private concern in Coimbatore for the establishment of an iron plant. This statement has apparently been misunderstood by some to mean that the Government have given up the idea of establishing an iron and steel plant in the Salem district as a State undertaking. These fears are without foundation. The establishment of a few small pig iron plants by private enterprise will not preclude the establishment of a large plant in the public sector, which continues to be the objective of the Government.

37. The question of establishing an iron plant in Salem has been engaging the attention of the Government from a long time. The iron ore deposits of Salem are fairly extensive, but they are on the whole, of low grade. The raw materials for iron smelting are, besides iron ore, limestone and metallurgical coke. Of these, limestone of the requisite quality is available within the district, but coal does not occur anywhere in Madras State and its procurement from West Bengal or Bihar is precluded on account of its high cost. It may not, therefore, be an economic proposition to convert the low

[25] Press Note No. 29, dated 17th June 1957—G.O. No. 2137, Industries, Labour and Co-operation, dated 24th June 1957.

grade ores of Salem by the conventional blast furnace method.

38. It is, however, known that in Germany and other countries a method has been found for turning even the low grade iron ores to account by reducing them in what is called "low shaft furnace". This process does not require superior coke of metallurgical grade, but can be worked with low grade coal or lignite. But, so far, this method has not been adopted in India. The Government of India have recently sanctioned the installation of a plant for the manufacture of iron from low grade ores on a pilot plant scale in the National Metallurgical Laboratory, Jamshedpur using non-coking coals. Bulk samples of Salem ores have been sent to the Laboratory for preliminary tests on sintering and reduction. The pilot plant trials will take some time, and it is hoped that, by then, lignite from the Neyveli mines would be available and it would be possible to take a final decision regarding the installation of a full scale iron manufacturing plant in Salem district.

39. Pending the installation of such a plant by the State, one or two industrialists have come forward to put up small pig iron plant in the Salem area with a capacity not exceeding 15,000 tons per year. The capital outlay on such projects is comparatively small, i.e., about Rs. 40 lakhs. The Government of India, with the concurrence of the State Government, have granted a licence to Messrs. Textool Company, Limited, Coimbatore, for the installation of a small pig iron plant. The company's proposal is to crush and concentrate by magnetic separation at site, the iron ore found at Salem and to sinter and reduce the concentrated ore in the company's factory at Coimbatore. More such small pig iron plants would be feasible and the Government will welcome proposals in this regard from the industrialists.

40. The Government have also constituted a State Industries Development Committee consisting of the Minister for Industries as Chairman, 5 official members, viz., the Development Commissioner, the Secretary, Industries, Labour and Co-operation Department, the Director of Industries and Commerce (Secretary), the Chief Engineer (Electricity) and the Chief Engineer, Public Works Department (General) and 14 non-official members chosen from reputed industrialists of the State. The function of the Committee is to consider how best industrial development in the State could be accelerated by undertaking (if necessary, by constituting sub-committees), detailed examination of the economic and mineral resources of

the State and by collecting the data required for preparing project reports for starting as many industries as possible.[26]

41. Since the issue of the Press Note and the constitution of the above Committee, some reports have been received from the National Metallurgical Laboratory, Jamshedpur.[27] It may be mentioned here that the Government of India who were addressed in 1952 to take up the question of conducting experiments with Salem iron ores and Neyveli lignite on the analogy of similar experiments being in vogue in Belgium and other foreign countries had replied that a pilot low shaft furnace plant for producing pig iron from low grade iron ores using non-coking coals would be sanctioned for erection at the National Metallurgical Laboratory, Jamshedpur, and samples of Salem iron ore would be asked for by the Council of Scientific and Industrial Research for tests.[28] This plant has been inaugurated on 5th February 1959 by the Union Minister for Steel, Mines and Fuel. Pending the conduct of experiments in the above plant with the Salem iron ores and Neyveli lignite and arising out of references from Sri C. R. Pattabhiraman, M.P., and the Director, National Metallurgical Laboratory,[29] tests were carried out on beneficiation, sintering and reducibility of Salem iron ores with coking coals at the abovementioned laboratory[30]. These reports are given in the Appendices II to V. The essence of these reports are given blow.

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[26] G.O. Ms. No. 2230, Industries, Labour and Co-operation, dated 2nd July 1957.

[27] Preliminary report, dated November 1957, on beneficiation of low grade magnetite from Salem—Lodged No. 86007 H.II|57, Industries, Labour and Co-operation, dated 26th December 1957.

Investigation Reports (1) No. IR. 116|58, dated January 1958, on beneficiation of low grade magnetite from Salem, Madras, Part I, by Sarvashree S. K. Banerjee and P. I. A. Narayanan, (2) No. IR. 127/58, dated February 1958, on reducibility of Salem magnetite ore by Sarvashree N. Subramanyam and P. P. Bhatnagar and (3) No. IR. 127/58, dated July 1958 on sintering studies on the magnetic concentrate produced from low grade Salem magnetite ore by Sarvashree S. K. Banerjee and P. I. A. Narayanan, all of National Metallurgical Laboratory, Jamshedpur—Industries, Labour and Co-operation Department C. No. 25275 Ind. (Spl)|58.

[28] Letter to the Government of India, Ministry of Natural Resources and Scientific Research, No. 145659 P. & D. III|52-1, Development, dated 31st December 1952, letter from the Government of India No. 13 (39)|54-SR.I, dated 9th October 1954, and letter No. 134 Bd. X (13)/54, dated 27th December 1954, from the Council of Scientific and Industrial Research all in Lodgd. No. 145659 G|54, Industries, Labour and Co-operation, dated 31st December 1954.

[29] G.O. Ms. No. 312, Industries, Labour and Co-operation, dated 29th January 1957.

[30] Industries, Labour and Co-operation Department C. No. 25275 Ind (Spl.)/58.

42. In the preliminary report, dated November 1957[31] on the beneficiation of low grade magnetite from Salem, it is stated thus :

Five samples of the magnetite each weighing 4 tons from the (1) higher, (2) middle and (3) lower belts respectively of the Kanjamalai hills at Salem were received for beneficiation and sintering tests. As the identification marks had disappeared by the time they reached Jamshedpur, all the samples had to be mixed for investigation purposes. One or two bags of four of the samples could however be identified. The representative sample of the mixed ore was prepared and a portion crushed to-10 mesh for experimental work. Wet screen analysis of the -10 mesh sample and the examination of the various fractions showed that the quartz was the principal gangue and magnetite was fairly liberated at about -48 mesh size. The sample as received assayed Fe, 36·5; SiO , 44.2, Al_2O_3 1·92; CAO, 1·8; Mgo, 0·9; P, 0·09 and Tio 0·2 percent.

43. Dry magnetic separation at a low intensity of the sample at -35 mesh produced a concentrate assaying 60·3 per cent. Fe and 14·3 per cent SiO_2 with a recovery of 71·9 per cent. Magnetic separation at -48 mesh improved the grade to 61·7 per cent Fe for the same recovery. A preliminary wet magnetic separation of the -48 mesh sample yielded a concentrate assaying 61·0 per cent Fe and 13·3 per cent SiO_2 with a recovery of 90·0 per cent Fe.

44. The reducibility test should be regarded as an essential guide in assaying the suitability of any iron ore for its utilization in blast furnace or in other iron making units, either directly or after various agglomerating processes, such as sintering, nodulizing, pelletizing, briquetting, etc. Specimens of cubical shape, weighing approximately the same weight, were prepared by cutting and grinding the lumps of Salem magnetite ore and these were reduced at various temperatures and gas velocities. Tables I and II indicate the results of the tests carried out on the uncrushed ore.

TABLE I.

Effect of temperature on the rate of reduction of iron ore.

H_2 Gas velocity 900°C.C. per minute

Total time of reduction—70 minutes.

	Temperature oC	Per cent reduction.
1	700	50·41
2	800	68·6
3	900	47·7

[31] Lodged No. 86007 HII|57, Industries, Labour and Co-operation, dated 26th December 1957.

TABLE II.

Effect of rate of flow of hydrogen on the reduction of iron ore.

Temperature—900°C. Total time of reduction—70 minutes.

Rate of flow.		Per cent reduction.
1 800 C.C. per minute	.. ..	35·4
2 900 C.C. per minute	.. ..	47·7
3 1000 C.C. per minute	.. ..	53·08

45. It is observed that the reducibility of the ore increased with the increase in temperature up to 800° C while further increase of temperature reduces the reducibility. An increase in gas velocity promotes the reduction rate at 900° C. It is also observed that even though both the temperature and gas velocity increased the rate of reduction slightly, the overall per cent reduction never exceeded 70 per cent after 120 minutes.

46. The next series of experiments were carried out on the crushed and unconcentrated sample in order to get a homogeneous sample. The crushed magnetite ore was made into briquettes with dextrine as a binding agent and samples were prepared from these briquettes. The reducibility tests wer conducted on these samples at different temperatures and ga velocities. The test was conducted first on -10 mesh size sample and further concentration was being carried out fror these crushed sample. Table III indicates the results obtained on different mesh size and uncrushed ore.

TABLE III.

Effect of mesh size on the rate of reduction.

Rate of flow of hydrogen—1,000 C.C. per minute:

Temperature of reduction—900°C

Total time of reduction—70 minutes.

Mesh size.		Per cent reduction.
1 Lump ore	.. ..	53·08
2 –10 mesh	.. ..	62·0
3 –32+72	.. ..	77·6
4 –100 ..	.. ..	55·1

47. It is observed that the reducibility has a maximum value for –32+72 mesh samples.

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TABLE IV.

Effect of temperature on the rate of reduction.

Mesh size, –32+71; Rate of flow of hydrogen, 1,000 C·C. per minute. Total time of reduction 70 minutes.

	Temperature °C	Per cent reduction.
1	600	48·5
2	800	59·8
3	900	77·6
4	1,000	69·5

48. It is observed that a maximum reduction, 77·6 per cent, is obtained at 900°C and that the total reduction decreased at 1,000°C.

49. A preliminary experiment conducted at 800° C and 1,000 C.C. per minute hydrogen gas velocity with the concentrated ore of -32 mesh size analysing 65 per cent Fe and 8·5 per cent SiO_2 showed a percentage reduction of 71·99 per cent for 70 minutes and 84·14 per cent after 120 minutes respectively.

50. In the Investigation Report, dated January 1958, on the beneficiation of low grade magnetite from Salem, Part I, by Sarvashree S. K. Banerjee and P. I. A. Narayanan of the National Metallurgical Laboratory, the conclusions of the experiments made are summarised thus.[32]

Five samples of Salem magnetite were received for beneficiation and other tests. The combined sample assayed 36·5 per cent Fe, 44·2 per cent SiO_2, 1·92 per cent Al_2O_3, 1·08 per cent CaO, 0·09 per cent MgO, 0·2 per cent TiO_2 and 0·09 per cent P. The iron minerals in the samples were magnetite, hematite and goethite. The principal gangue mineral was quartz with small amounts of kyanite and Sillimanite. Over 90 per cent of the magnetite was liberated at -48 mesh size.

51. Dry magnetic separation of the sample at -48 mesh did not give encouraging results. Wet magnetic separation of the sample at -48 mesh produced a concentrate assaying 62·5 per cent Fe, 11·1 per cent SiO_2, with a recovery of 88·9 per cent Fe, whereas by employing a -65 mesh feed, the grade of concentrate improved to 64·3 per cent, Fe and 9·6 per cent SiO_2 for almost the same recovery. The liberated hematite was lost in the non-magnetic tailing.

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[32] Industries, Labour and Co-operation Department C. No. 25275 Ind (Spl.)/58.

52. Dry magnetic separation at -10 mesh followed by cleaning of the magnetic fraction by wet magnetic separation after grinding to -48 mesh gave a final concentrate assaying 61·98 per cent Fe and 12·1 per cent SiO_2 with a recovery of 86·5 per cent Fe. The results should be considered as satisfactory in relation to those obtained by straight wet magnetic separation at -48 mesh. The two stage process saves unnecessary grinding of about 25 per cent by weight of gangue which could be rejected at -10 mesh and requiring only the remaining 75 per cent to be ground to -48 mesh for final cleaning.

53. Tabling the sample at -48 mesh after classification yielded a combined concentrate assaying 67·0 per cent Fe and 6·5 per cent SiO_2 with a recovery of 76·8 per cent Fe. The recovery improved to 92·8 per cent Fe by mixing a concentrate II when the grade dropped to 65·2 per cent Fe and 8·8 per cent SiO_2. Tabling yieleded a better grade of concentrate than that obtained by magnetic separation, though the recovery was somewhat lower. For a concentrate of grade about 62·5 per cent Fe at -48 mesh size, tabling and magnetic separation could be expected to give the same recovery of about 87 per cent in hematite which got lost by magnetic separation. The results obtained by tabling a -65 mesh feed were not encouraging due to high slime loss.

54. Pilot plant tests were carried out with the ore employing tabling as well as magnetic separation. Tabling the sample yielded a concentrate assaying 67·0 per cent Fe and 5·56 per cent SiO_2 with an iron recovery of 77·6 per cent. The results compared very well with those obtained in the batch tests. Higher recovery can be obtained by collecting a correspondingly lower grade of concentrate.

55. A single pass of the ore through the wet magnetic separator yielded a magnetic product assaying 62·1 per cent Fe and 13·2 per cent Sio_2 with a recovery of 81·2 per cent iron in the product. The grade and recovery were lower than those obtained in small scale laboratory tests because the magnetic intensities and other factors could not be adjusted to optimum level at Ghatsila. The feed was also somewhat coarser containing 12·5 per cent by weight in the +65 mesh fraction, as compared to a -65 mesh feed employed for the batch tests. Better results should be obtained in the process by employing a finer feed and carrying out the magnetic separation under optimum conditions. The presence of appreciable amounts of hematite and goethite was responsible for the loss of iron in the magnetic fraction.

56. In yet another report, dated February 1958, on the reducibility of the Salem magnetite ore written by Sarvashree M. Subrmaniam and P. P. Bhatnagar, it is stated thus ;

An attempt was made to assess the reducibility of Salem magnetite iron ore based on hydrogen reduction of lumps with briquettes made thereof. The temperature of reduction varied from 700°C to 100°C with different rates of hydrogen flow. Reduction rate was observed to considerably slow down after 70 per cent of reduction was completed. Reduction experiments were also conducted after table concentration of the magnetite ore, these concentrates containing 5-6 per cent silica. Tests were likewise undertaken on concentrate containing 13 per cent silica (SiO_2)) obtained after wet magnetic separation of the raw ore. These studies showed that reducibility of the ore concentrates compared favourably with that of high grade hematite iron ores used in India at present for iron production.

The Salem ore is mainly a mixture of magnetite and quartz in equal proportions, containing about 35 to 40 per cent iron, medium-to-low phosphorus and very low sulphur. A typical analysis of the ore is, FeO 5·04 per cent, Fe 36·5 per cent, SiO_2 44·?0 per cent, Al_2O_3 1·92 per cent, CaO 1·8 per cent. MgO. 0·90 per cent, P.O.093 per cent, and loss on ignition 0·2 per cent. On account of the high silica content the ore is not suitable for direct reduction in the blast furnace, as it will not only form compounds that are difficult to reduce but the slag volume will be too voluminous to be profitably handled

57. The report then describes the various tests made and concludes thus. Reducibility tests carried out on the ore concentrates obtained after (1) crushing and tabling and (2) wet magnetic separation indicated that the ore concentrates obtained possess optimum reducibility. These concentrates after agglomeration could be used for pig iron production in the normal blast furnace. The product obtained after wet magnetic separation containing 13·4 per cent silica is in no way inferior to the concentrates containing 5·0 to 7·0 per cent silica as far as the reducibility tests are concerned. The high silica content will, however, increase the slag volume with its consequent operational difficulties.

58. In a still further report, dated July 1958[84] on the sintering studies on the magnetic concentrate produced from

[83] Industries, Labour and Co-operation Department C. No. 25275 Ind (Spl.)/ 8.

[84] Idem.

low grade Salem magnetite ore written by Sarvashree S. K. Banerjee and P. I. A. Narayanan of the National Metallurgical Laboratory, the authors have pointed out the advantage of sintering the ore before smelting in the blast or low shaft furnace as below :—

59. " The possibility of using the magnetite concentrate which after upgrading is in the form of fines, for smelting in iron blast furnace or low shaft furnace depends upon the development of a process for agglomerating the fines into lumps. Though there are various methods that could be employed for the purpose, viz., briquetting, pelletising, sintering, etc., the last, i.e., sintering appears to be most promising for this ore particularly since the final sinter will be in the form of a more easily reducible product than magnetite itself which is known to be more difficult to reduce and smelt.

60. The report then goes to describe what good sintering is, the procedure adopted in conducting the sintering tests at the laboratory and concludes as follows :—

" The sinter mix (weighing about 35 lbs.) consisted of the magnetite concentrate (17·5 lbs) limestone (4.5 lbs), coke (2·5 lbs), water (3·5 lbs) and sinter fines (7·0 lbs). Coke, water and limestone were varied to obtain the best sinter. The basicity $\frac{(CaO + MgO)}{(SiO_2 + Al_2O_3)}$ of the charge was varied from 0·6 to 1·2 by varying the limestone content of the charge. The time of sintering decreased with increase in limestone contents of the charge. Taking into consideration both time and strength, a basicity ratio of 0·85 was found to be optimum for satisfactory sinter. It was observed that the time of sintering decreased with increase in coke content. The amount of coke necessary to produce the best sinter was found to be 7 per cent. Higher coke content in the charge produced fused sinters. Sintering time increased with increase in water content of the charge. The time of sintering was 21 minutes for a water content of 9 per cent in the mix. Considering both time and strength this was taken as optimum. Thus, the optimum time for sintering was 21 minutes for a charge with a basicity ratio of 0·85 and 7 per cent coke and 9 per cent water. Sintering time varied inversely with suction. Increase in the quantity of sinter fines over 20 per cent was found to reduce the sintering time but the sinter strength was lower. The sinters produced during the tests were found to be strongly magnetic containing mostly magnetite with some hematite embedded in a matrix of slag. The top of the sinter was always found to be more friable than either the middle or bottom layers."

61. The National Metallurgical Laboratory has yet to conduct experiments on the possibility of reducing Salem iron

ores using Neyveli lignite in the Low Shaft Furnace Plant erected there and inaugurated on 5th February 1959 by the Union Minister for Steel, Mines and Fuel.

62. Pending the conduct of the experiments mentioned in paragraph 61 above and with reference to the reports of results of tests already conducted by the United States Bureau of Mines and certain foreign firms such as, Elektrokemisk, A/s, Oslo, Norway, the Government of India have been addressed to take up the question of planning and setting up at Salem in the Third Five-Year Plan period of a Low Shaft Furnace Plant for reducing the Salem iron ores using the Neyveli lignite with a capacity of 500,000 tons of pig iron per annum for which 500,000 tons of lignite coke by High Temperature Carbonisation Process would be required. It is hoped that this proposal will be examined by a Technical Committee to be constituted by the Government of India. The Neyveli Lignite Corporation (Private), Limited, has also been addressed to take steps to set up in the Third Plan period the High Temperature Carbonisation Plant for the production of lignite coke for reduction purposes[35].

63. With a view to examine the possibility of exporting Salem iron ores, Sarvashree Banerjee and Narayanan have at this Government's request, also furnished a list of equipments required for a Beneficiation plant with a capacity of 200 tons of ore per day of 24 hours, which will produce 100 tons of concentrate and estimates of capital and working costs. The total cost of machinery and plant including the cost of erection is estimated at Rs. 31,00,000. It has also been reported that the approximate cost of beneficiation to produce one ton of concentrate will be Rs. 42 roundly. The question of setting up the beneficiation plant is being further examined[36].

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[35] Industries, Labour and Co-operation Department C. No. 154414 Ind. (Spl.) |58.

[36] Industries, Labour and Co-operation Department C. No. 25275 Ind. (Spl.) |58.

APPENDICES.

APPENDIX I.

(See paragraph 33, Chapter I.)

G.O. No. 4832, Development, dated th November 1944.

[MINES—GEOLOGICAL SURVEY OF INDIA—THE IRON ORE DEPOSITS OF SALEM AND TRICHINOPOLY DISTRICTS—FINAL REPORT—PUBLISHED.]

READ—the following papers:—

From the Director, Geological Survey of India, dated 12th July 1944, No. 14005/1812.

G.O. No. 1781, Development, dated 1st October 1944.

Order—No. 4832, *Development, dated* 11*th November* 1944.

The report on the iron ore deposits of parts of Salem and Trichinopoly districts by Dr. M. S. Krishnan, Geologist and N. K. N. Aiyengar, Assistant Geologist, Geological Survey of India, will be published.

(By order of His Excellency the Governor)

T. SIVASANKAR,
Secretary to Government.

THE IRON ORE DEPOSITS OF PARTS OF SALEM AND TRICHINOPOLY. DISTRICTS.

(*By M. S. Krishnan, M.A., Ph.D., Geologist, Geological Survey of India and N. K. N. Aiyengar, M.A., Assistant Geologist, Geological Survey of India.*)

I.—INTRODUCTION.

The magnetite-quartzites ores of the Salem-Trichinopoly Arcot region constitute the most valuable group of iron ore deposits in the Madras Presidency. For many centures iron and steel have been manufactured in these districts in small indigenous furnaces but the industry became extinct at about the dawn of the present century when cheap iron, manufactured in Europe, began to make its appearance in the Indian market in increasing quantities. The ores used by the Indian craftsmen were not necessarily derived from the large and rich deposits but were taken from easily accessible and easily worked out crops, and included magnetite, hematite, limonite or even lateritic material.

The iron ores of the Salem district and the surrounding region were taken up for investigation by the Geological Survey of India in pursuance of the programme of mineral development contemplated by the Government of Madras. They now take on an added importance in view of the fact

that the development of the iron and steel industry must figure prominently in any scheme of post-war industrial development.

The field work for this enquiry comprised the mapping of the bands of iron ore and the collection of fairly representative samples from the more important ones. Though all the known occurrences in the Salem and Trichinopoly districts have been examined, it was not possible to map systematically all the area in the abovementioned districts. It is, therefore, possible that, in addition to deposits present in the North and South Arcot districts a few more ore bands may come to light as a result of systematic mapping but it is unlikely that any such bands will be of great importance.

The field work was carried out by the second author (N. K. N. Aiyengar) under the general supervision of the first author. Analyses and tests were carried out in the laboratories of the Geological Survey of India at Calcutta, the Indian School of Mines at Dhanbad, and in the Geology Department of the Presidency College, Madras. Our thanks are due to the chemical staff of the Geological Survey of India and the Indian School of Mines and to several of our colleagues in the Madras Party (Geological Survey of India) for the help they have given us in the laboratory.

The area examined includes parts of the Salem, Attur, Harur, Namakkal and Rasipur taluks of the Salem district, and the Musiri and Perambalur taluks of the Trichinopoly district. It lies between the north latitudes 11° and 12° and east longitudes 78° and 79°, comprised in the Survey of India standard (1 inch = 1 mile) sheets 57 L/12, 57 I/2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15 and 16.

The present report deals mainly with the description of the various deposits examined by us and their nature and composition. Estimates of reserves of ore are given. In the latter part of the report the utilization of the deposits is discussed briefly in the light of the present knowledge, though this question must be examined in detail by metallurgists of experience before any practical results can be achieved.

II.—PHYSICAL FEATURES.

The iron ore region is generally hilly and is divided into two unequal portions by the Attur valley which extends in an easterly direction from Salem towards Cuddalore. The Northern area comprises the Shevaroy, Chitteri and Kalrayan hills which spread over a distance of 50 miles from west to east. The northern extension of these is the Tirthamalai in which also some important iron ore deposits occur. In the southern area there are the Kollaimalai and Pachchaimalai, as also the Talamalai and Bodamalai. The best known deposits are found in the Kanjamalai and Godumalai, both of which are comparatively small isolated hills in the western part of

the Attur valley. The tallest hill masses are the Shevaroys and the Kollaimalais which rise to well over 4,000 feet altitude.

There are no rivers of importance in the area under consideration. The small streams traversing it join either the Cauvery in the west or south, or the Ponnaiyar in the north, or the Vellar in the east. The rainfall is variable, the hills receiving 30 to 50 inches or more according to their location and altitude, and the plains barely 20 to 25 inches. The steady deforestation of this region is responsible for the increasing soil erosion and advancing aridity and lowering water table. Many areas which were covered by fairly good forests within living memory of the older inhabitants are now covered with thorny shrubs or under poor cultivation. The deforestation is at least partly responsible for the periodical droughts and the recurring semi-famine conditions, especially in the Salem district.

Only the larger hills like the Shevaroys, Kalrayan Hills, Chitteri Hills, Tirthamalai and Pachchaimalai are wooded. The others support a thin forest or none at all. The 'reserved forest' of Kanjamalai contains merely thorny shrubs having little or no value even as firewood. Some of the well wooded hills are the sources of bamboo and timber for the region surrounding them.

Yercaud in the Shevaroys is a cool and healthy place used as a hill station during the summer. There are numerous coffee estates in these hills. Some of the other hills, especially the Kollaimalai, Pachchaimalai and Chitteri hills, are highly malarial.

Communications.—The iron ore area is traversed and surrounded by a number of fairly good roads. Road transport is, therefore, not difficult here. The main broad gauge track of the South Indian Railway connecting Madras and the West Coast passes close to the Shevaroys and the Kanjamalai, while a metre gauge branch line (from Salem to Vriddhachalam and Cuddalore) passes through the Attur valley at the foot of the Godumalai, and between the Chitteri and Kalrayan hills on the north and Kollaimalai and Pachchaimalai on the south.

III.—PREVIOUS LITERATURE.

There is a fairly voluminous published literature on the iron ores of Salem and neighbouring districts dating from the early part of the last century. The earliest references are mainly accounts of journeys through these districts by officers of the East India Company or other travellers. They contain notes on the geology and minerals and particularly good descriptions of iron and steel making by the local craftsmen. Amongst these, the works of P. M. Benza (1836) and T. J. Newbold (1845) are noteworthy. E. Balfour summarized the knowledge of the iron ore deposits of the Madras Presidency in a work published at Madras in the year 1855. The nature and properties of the wootz steel manufactured here and elsewhere in India were

investigated by several scientists in the latter part of the eighteenth and earlier part of the nineteenth centuries. Accounts of the iron works established mainly through the efforts of J. M. Heath and which functioned between 1830 and 1870 have been given by Heath and Princep.

The first comprehensive account of the geology and mineral resources (including iron ores) was given by W. King and R. B. Foote in the Memoirs of the Geological Survey of India published in 1864. Much of this information is also contained in the *Salem District Gazette* by Le Fannu published by the Government of Madras in 1883.

Between 1890 and 1892, Mr. T. H. Holland (later Sir Thomas Holland) examined the iron ore deposits of the southern districts of the Madras Presidency and published a report under the auspices of the Imperial Institute of London. This contains several analyses of the ores for the first time. Since then some of the deposits, especially those in Kanjamalai, seem to have received the attention of private interests. Dr. V. S. Dubey and Mr. C. Karunakaran examined the Kanjamalai deposits in 1937–38 and submitted a report thereon to the Government of Madras. A summary of this has been published in the journal of the Geological Mining and Metallurgical Society of India for 1943. The same number of the journal also contains papers by Mr. S. Krishnaswamy and Mr. K. K. Sen Gupta in which remarks about these deposits will be found.

The indigenous industry.—Several observers have published first-hand accounts of the processes used by the men engaged in the manufacture of iron and steel in South India.

Any type of iron ore was used, which was available in the neighbourhood. It may be hematite or magnetite in massive form or mixed with quartz; it may be magnetite sand collected from streams; or limonitic or lateritic material fairly rich in iron. The ore had generally to be in a form easily disintegrated by the hammer. It was crushed and winnowed in strong breeze to separate the lighter quartz from the heavier ore mineral. Sometimes the crushed ore was washed in water to effect concentration.

Smelting.—The smelting was carried out in small furnaces built of clay. The furnaces used in Salem in the nineties (as observed by Sir Thomas Holland) were circular in cross section, about 4 feet high, 2 feet in diameter at the bottom and tapering upwards to about 6 inches diameter at the top. The furnaces used in Malabar were larger, with rectangular cross section, 10 feet high, 3 to 3½ feet from side to side and 2 to 2½ feet from front to back. The air blast for aiding combustion was supplied by leather bellows. The ore and charcoal were fed from the top. The smelting took 3 hours in the Salem furnaces, producing a bloom 15–20 lb. in weight, whereas it took 48–60 hours in Malabar and yielded blooms weighing

500-600 lb. The iron bloom contained a certain amount of slag inclusions which were removed by beating while hot. The blooms were ready to be worked into wrought iron or were further treated to make steel.

Steel making.—Wrought iron was carburised in crucibles made of clay and rice husk. The crucibles were usually about 6 inches long and 3 inches in diameter at their maximum. The charge consisted of pieces of wrought iron with which was also placed charcoal amounting to about 5 per cent (by weight) of the iron. The mouths of the crucibles were closed after the charge had been placed. Twenty or 25 crucibles were then placed on the slightly arched bottom of the furnace. Below this arched bottom a bottle-shaped cavity was left which served as the slag pit. After the first lighting up, charcoal for further combustion was added from above. Bellows supplied air through tuyeres which were located just above the neck of the pit. The centrally placed crucibles were ready for removal after smelting with continuous air blast for two hours. The crucibles at the sides were gradually moved to the centre and removed after a period known through experience. The molten contents of the crucibles solidified into conical ingots weighing around 10 lbs. each. This process was the fore-runner of the cementation process in Europe. The product was the celebrated *wootz steel.* Wootz steel was made in the Trichinopoly district in the 1890's but not in Salem, though earlier in the century it was certainly made in Salem also.

The steel made in Salem in the ninetees was really *decarburized cast iron.* During the manufacture of wrought iron, a quantity of molten beads of iron, high in carbon, are produced. These beads or shots are pounded to remove the adhering particles of slag and smelted in a pit over a charcoal fire supplied with air from bellows. The process of steel making is complete in half an hour, when a cake of steel with a covering of slag is got. The slag is easily removed by hammering.

Though some people had attained skill in producing a very good quality of steel, all observers agreed that there was an enormous wastage of ore, metal, heat energy and time. No flux was used, there being consequently a heavy loss of iron in the slag. The furnaces were of very poor construction and there was much waste of heat. The iron frequently never went beyond a pasty condition and contained particles of undecomposed ore. Everything was done empirically on rules handed down by tradition.

Large-scale industry on modern lines.—The first proposal to use modern methods (then in vogue in Europe) for smelting iron in the Madras Presidency was made by Josiah Marshall Heath about the year 1818 when he was a civil servant under the East India Company. He resigned from the service soon after and spent five years in England learning the details of manufacture at first hand. He returned to India in 1830 and obtained exclusive rights from the East India Company to manufacture iron on a large scale in the Madras Presidency. Works were erected at Porto Novo shortly after. In 1833, a new company

called the Porto Novo Steel and Iron Company was organized to take over and enlarge the works. Furnaces were also built at Beypore in Malabar. The undertaking was, however, unsuccessful and in 1849, the East India Company had a claim against Heath's concern for Rs. 8¼ lakhs. A new company was formed in 1849, called the East India Iron Company with a capital of £400,000. They settled the claims of the East India Company by paying them £10,000 and obtained exclusive rights for a period of 30 years at the annual rental of £500, for taking ore from Government lands in the Salem, South Arcot, Coimbatore and Malabar districts. They erected a blast furnace at Tiruvannamalai (North Arcot district) and another at Pulampatti (11°39′ : 77° 46′) on the Cauvery between Bhavani and Mettur. These were also unsuccessful. The operations ceased at Pulampatti in 1858; at Porto Novo in 1866; and at Tiruvannamalai and Beypore in 1867. The compnay relinquished all their privileges in 1874.

In 1875 the Napier Foundry Company was established at Madras to manufacture pig iron and was granted an area of 42 square miles of forest in North Arcot for making charcoal. This agreement was terminated in 1877.

The operations at Pulampatti have been described by W. Maylor. The ore used was high grade 'float' from around the foot of the Kanjamalai, which was about 28 miles distant from Pulampatti. Charcoal came from the forests near Sholapadi apparently Kovil Cholapadi—11°54′: 77° 52′) about 16 miles above Pulampatti on the Cauvery. The cost of ore and charcoal delivered at the works was around Rs. 7 and Rs. 8 respectively per ton. As the operations were not continuous, the charcoal consumption was heavy, about 37 cwt. per ton of iron produced. The output of iron per week was 45 to 50 tons. The cost of manufacture of iron at Pulampatti and Porto Novo 1858 are given as Rs. 40 and Rs. 56 per ton respectively, the difference being mainly due to higher cost of transport of ore and charcoal to Porto Novo.

The work of King and Foote revealed the existence of several important deposits in this region, the chief amongst which were in Kanjamalai, Godumalai, Talamalai-Kollaimalai and Tirthamalai. They have also pointed out the existence of numerous small exposures of ore in the region. The important bands are marked on the map accompanying their paper in the Memoirs of the Geological Survey of India.

The results of Sir Thomas Holland's work in the early nineties are given in three papers, one of which is mainly geological, the other two dealing with the ores, the then status of the iron industry and the question of fuel supply. Analyses of the ores collected from several places are given, though some of them refer obviously to pieces of high grade ore weathered out of the ore bands. Holland recognized that the ores are merely mixtures of quartz and magnetite, varying in texture from coarse material containing almond-shaped pieces of ore up to three-fourths of an inch across, to very fine-grained or aphanitic rock. With regard

to composition Holland wrote in his preliminary report (*Rec. Geol. Sur. India*, XXV, pages 137–138) as follows:—

"The Dannemora (Sweden) ore employed yielded on an average below 50 per cent of the metal, varying between 25 and 60 per cent, whilst in the Salem district it is possible to obtain an almost inexhaustible supply of ore with an average of nearly 60 per cent iron. This result is calculated from the average mineral composition stated by Messrs. King and Foote, and agrees with the rough calculations of my own on crushed samples as well as the estimate given by Balfour. I have collected a large number of typical specimens which I hope to subject to analysis, the results of which will be embodied in the final report. I know of no published analysis of Salem ore giving the results of a search for such impurities as phosphorus, sulphur and manganese but from the reputation of articles of steel which have, in times past, been made from these ores by the well-known Arunachala Achari and others, they must have been very free of at least both phosphorus and sulphur . . . Fluxes are used in most places for the purpose of economizing the iron, lime replacing the iron in the compound silicate of the slag, but in this district the ore itself is so inexpensive that the manufacturers can afford to lose a highly ferriferous slag for the sake of cleansing from phosphorus. Whilst I have no doubt that these facts may account in some measures for the purity of the iron and steel produced by the highly wasteful process of the native smelters, who use no flux beyond that afforded by the ash of the charcoal employed as fuel, it is still probable that the Salem magnetite is comparatively free from this impurity (phosphorous) . . . ".

The following analyses of iron ores collected by Holland from the Salem-Tiruchirappalli region are quoted from the Imperial Institute Journal for June 1896, Volume II, page 223:—

Number and locality.	F	F_3O_4	F O	S
799 Kanjamalai	68·95	75·20	20·07	0·16
812 Do.	36·44	48·10	3·56	0·10
813 Do.	35·73	38·13	11·62	0·29
815 Do.	70·06	66·72	30·03	0·20
873 Do.	63·57	70·98	17·72	0·29
874 Do.	66·96	69·29	23·73	0·10
793 North flank of Kollaimalai (three miles from Na.nagiripet).	69·75	74·77	22·38	0·30.
795 orth flanks of Kollaimalai.	31·92	41·00	4·14	0·30
796 Do.	32·17	40·44	4·96	0·22
802 Do.	37·38	51·10	2·07	0·13
810 Do.	68·06	77·95	17·36	0·26
800 Namagiripet	68·40	78·07	17·68	0·89
821 Mur gathimalai (West-south west of Attur).	42·93	53·75	6·78	0·68
801 M.thurili (near Mallikari).	63·43	77·64	11·67	0·25
808 Do.	60·21	68·12	16·10	0·19
899 Do.	65·22	77·51	14·09	0·10

Number and locality.	P_2O_5	Insol.	Al_2O_3	H_2O
799 Kanjamalai .. .	0·30	1·04	2·45	0·59
812 Do.	..	46·95	0·61	1·02
813 Do.	0·62	48·45	0·46	1·10
815 Do.	..	1·72	0·82	0·72
873 Do.	..	8·89	1·18	0·95
874 Do.	..	3·17	2·16	1·72
793 North flank of Kollaimalai (three miles from Namagiripet).	..	0·55	1·00	0·52
795 North flank of Kollaimalai.	0·30	53·22	0·12	1.35
796 Do.	..	53.98	..	0·67
802 Do.	..	45·19	0.86	1·10
810 Do.	..	3·43	1·98	0·70
800 Namagiripet	..	1·74	1·49	0.73
821 Murugathimalai (West-south-west of Attur).	..	36·44	0·28	2·00
801 Muthurili (near Mallikarai).	..	9·56	0·24	0·72
808 Do.	..	14.26	0.21	0·72
899 Do.	..	6·51	1·15	0·69

It will be noticed that several of the above analyses are those of high grade ore, presumably weathered-out lumps of magnetite from the ore beds. The major impurity is silica which, as quartz, is the chief associate of the ore mineral. The sulphur is high in these analyses but later analyses show very little of this constituent.

Some other samples collected by Sir Thomas Holland were analysed in the laboratory of the Geological Survey of India:—

Register number and locality	Fe	S	P	Insol.
I. 445, Perumamalai ..	40·07	0.012	0·090	41·74
I. 446, Kollamalai ..	35·76	0·008	0.093	47·49
H. 156, Kanjamalai ..	36 55	0·005	0·097	48·00
I. 448, South-east of Namagiripet	30·46	0·006	0·119	54·49

Mr. C. S. Middlemiss of the Geological Survey of India also made collections from the lowest band of the Kanjamalai when he worked in the Salem district in the years 1894 and 1895. Three of the sample which were analysed, gave the following iron content (*See Rec. Geol. Surv. India* XXIX, page 38, 1896):—

Specimen No.	Fe.	Sp.Gr.
10/212 (aphanitic)	35·00	3·36
10 243 (coarse)	34·39	3 53
10/239 (coarse)	36·66	3·54

Mr. Middlemiss also collected 32 samples at 200 ft. intervals across the whole thickness of 70 feet of the lowest band. These samples were sent to the Imperial Institute, London. We have not seen the detailed analyses of these but it is known that the average analyses of all these samples was:

Fe. 39.02 per cent; Silica, 42.36 per cent; S. 0.3 per cent; P. 0.13 per cent.

After Sir Thomas Holland reported on these ores, the Government of Madras pursued the question of the feasilibity of manufacture of iron in Salem and collected useful data on the forests of the district and the availability of timber for making charcoal, and the cost of importing coal from Singareni and elsewhere. They sought also the expert advice of Mr. Jeremiah, Head in England, who furnished a valuable report covering all aspects. The information connected with these enquiries is contained in Madras Revenue Department Proceedings No. 420, dated the 4th July 1895, and Despatch No. 75, dated the 2nd July 1896, from the Secretary of State for India to the Government of India.

In discussing a paper on Swedish iron ores (' Gellivare Iron ore Mines ' by H. Bauerman, *Journ. Iron and Steel Inst.* I V. pages 65–67, 1899), Prof. H. G. Turner remarked that the visible outcrops of the Kanjamalai exceeded in size any individual deposits he had seen in Sweden. He also stated that the Government of Madras sent an Engineer to the Kanjamalai who collected a large sample and sent it to London. The material received was quartz-magnetite-schist having an iron content of 38 per cent. When concentrated after crushing, the iron content rose to over 50 per cent.

	Fe.	P.
Before crushing	38·65	0·065
After crushing (to 1/8 inch) concentration	57·73	0·045

Messrs. Gaudart & Co. of Pondicherry had the ores of Kanjamalai examined in 1914 by W. Chowdhry, Consulting Geologist. In his report, to which we have had access in the files of the Geological Survey of India, Dr. Chowdhry stated that the two types of ore here are coarse magnetite-quartz-schist and a dark aphanitic rock (very fine grained mixture of quartz and magnetite). The base of the hill was found covered with debris of high grade magnetite. The lowest band was found to have a thickness varying between 75 and 125 feet, with an average of 100 feet. The analyses of samples collected by Dr. Chowdhry are given below. He regarded the ore as suitable for magnetic concentration after crushing, during which process the phosphorus would probably be considerably reduced.

No.	Fe.	SiO2	TiO2	P.	S.	MgO.	CaO
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
I	50·46	23·88	2·56	0·124	Tr.	0·98	4·02
II	61·40	18·16	2·16	0·030	Tr.	0·36	2·19
III	34·44	44·30	0·14	0·037	0·065	0·36	0·12
IV	36·10	43·87	0·18	0·137	Tr.	0·41	1·69
V	38·34	39·51	0·29	0·123	Tr.	1·13	0·70
VI	68·27	1·15	0·60	0·031	0.013	0·03	.0·10
VII	36·27	41·46	0·16	0·094	Tr.	0·84	0·39

I, II, Massive ore.

III, IV, V, Quartz-magnetite-schist.

VI. Pebbles of magnetite.

VII. Dark aphanite ore.

A 5-ton bulk sample of the ore was sent to London and the analysis reported was as below:—

	per cent.	
Fe_2O_3	47·60	Fe=44·2.
FeO	14·04	
Al_2O_3	11·86	
SiO	22·25	
TiO_2	1·92	
CaO	1·27	
MgO	0·72	
P	0·123	
S	0·021	
As	0·005	
Cu, Pb, Zn, Mn, Ni	Nil.	

Messrs. Gaudart and Company had also a sample sent to Fried Krupp's in Germany who pronounced it amenable to magnetic concentration. Their tests revealed that the iron content improved from 45 to 68·5 per cent and that the phosphorus and titanium were reduced to 0·04 and 0·58 per cent respectively. The power consumption in a drum type magnetic separator used for concentrating the ore was found to be 1·5 h.p. hour per ton of ore.

The Geological Survey of India sent Dr. Murray Stuart in 1919 to Salem to take samples of the Kanjamalai ores for conducting concentration tests with the electro-magnet. Dr. Stuart collected three large samples, each representing a cut across the lowest band of the Kanjamalai. The iron contents of the samples were as shown below:—

	Iron per cent.
(1) North-east end of hill (3 tons)	39·03
(2) 100 yards west of the above (3 tons)	38·60
(3) Sout-east end of hill (5 tons)	37·12

The samples were transported to Dhalbhumgrah in Bihar where the Great Indian Phosphate Company had a crusher and magnetic concentrator. The samples were crushed to 3/8 inch size, but when passed through the electro-magnetic separator there was no improvement at all in the iron content. Though it was clear from this that much finer crushing was needed, no attempt seems to have been made to test after finer crushing.

Fresh interest was created in these deposits on the completion of the Mettur Project (combined irrigation and hyro-electric). In 1935, at the suggestion of the Director of Industries, Madras, a piece (Reg. No. 10/241 in the Geological Survey of India collections) representing the average medium gained quartz-magnetite-schist collected by Middlemiss was crushed to 10 mesh and passed through a (not very efficient) laboratory electro-magnet in the Geological Survey of India, Calcutta. The original ore contained 39.01 per cent iron. The concentrate, which was 79 per cent by weight of the material taken, analysed

56·95 per cent, the tailings containing only less than 5 per cent It is, therefore, clear that the average (coarse and medium grained) ores must be crushed to 10 mesh or finer to get a good concentrate, but the fineness of crushing can be adapted to the texture of the type of ore to be dealt with. It is desirable to get the maximum enrichment in the concentrate with the minimum expenditure of energy in crushing and, in general, a concentrate containing at least 90 per cent magnetite should be aimed at.

Before the present investigation was taken up, the Government of Madras invited Dr. Dubey of the Benares Hindu University in 1938 to examine the ores of the Kanjamalai and the feasibility of melting them. Dr. Dubey, assisted by Mr. C. Karunakaran, submitted a report in due course, a summary of which has been published in the *quarterly Journal of the Geological Mining and Metallurgical Society of India*, Vol. XV, pages 3–20, 1943. The above paper gives the results of analysis of several samples of ores taken from different parts of the deposits:

No.	*$Fe\,O_4$.*	*SiO_2.*	*Al_2O_3.*	*CaO.*	*MgO.*	*H_2O.*	*Total.*	*Sp. Gr.*
1 ..	52·05	42·77	1·15	1·41	1·80	2·09	100.55	3·50
2 ..	52·54	43·25	0·25	0·92	2·02	1·45	100·42	3·51
3 ..	50·05	42·16	1·20	2·60	2·60	1·54	100·15	3·35
4 ..	46·20	43·22	5·89	1·51	0·82	2·50	100·14	3·47
5 ..	44·83	48·09	1·00	3·32	1·84	1·67	99·75	3·58
6 ..	44·03	48·70	0·87	1·37	3·87	1·04	99·88	3·43
7 ..	44·20	46·71	4·17	1·63	1·36	2·50	100·58	3·50
8 ..	44·98	46·40	3·49	2·75	1.08	0·89	99·59	3·32
9 ..	45·26	49·50	1·70	1·90	2·02	1·23	100·61	3·38
10 ..	46·40	49·50	2·11	0·27	0·92	1·53	100·77	3·45
11 ..	51·97	43·45	1·30	1·02	0·98	1·97	100·69	3·57
12 ..	53·18	42·94	0.14	0·85	0·80	2·32	100·23	3·60
13 ..	54·20	41·30	0·04	1·60	1·83	1·40	100·37	3·35
14 ..	52·61	42·69	1·27	2·03	1·01	1·04	100·77	3·55
15 ..	55.45	37·93	2·20	2·11	2·06	1·02	100·77	3·52
16 ..	55·30	25·68	2·46	9·00	6·32	1·87	100·63	3·67
Average ..	49·58	43·33	1·82	2·08	1·91	1·62	100·34	3·42

Note.—Specimens 1–3 from the first band; 4–6 from the second band; 7–8 from the third band; 10–12 from the fourth band; 13–16 from the fifth band. Only the calculated Fe304 content is given in the analysis instead of Fe203 and FeO. Titania is said to be absent in all while P and S are said to have been found only in traces, which is indeed surprising.

Of interest to the present enquiry is the fact that during the last 20 years a charcoal blast furnace has been operating at Bhadravati in the Mysore State. The capacity has been increased from 40 tons to about 80 tons per day and a steel plant has been added a few years ago. Timber from a specially reserved forest area in the State is carbonized and supplied to the blast furnace. The ore used is, however, hematite. The Mysore Iron Works were not making a profit while they manufactured only pig iron which was partly exported and partly used for making castings. But they began to be remunerative when

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steel making was commenced. These works have provided India with very valuable experience in smelting of iron ore with charcoal fuel. More recently two electric furnaces have been installed in Mysore for the manufacture of ferro-silicon and ferro-chrome.

IV.—GENERAL GEOLOGY.

The iron ore areas have not been mapped in detail but the observations made during the course of the examination of the ore occurrences are put together here. These are, of course, liable to be modified in the light of further data when it becomes possible to map the areas in detail. The chief geological formations met with here are—

(1) Biotite gneiss (oldest).

(2) Hornblende-gneisses, steatite, chlorite-schists, quartz-schists and quartz-magnetite-schists.

(3) Amphibolites and pyroxenites.

(4) Charnockites.

(5) Granites and pegmatites.

(6) Ultrabasic rocks, magnesite, chromite.

(7) Basic dykes (youngest).

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(1) *Biotite gneiss.*—The oldest rocks in this region appear to be the grey coloured, foliated gneisses generally containing a good amount of biotite which is sometimes altered partly to chlorite. They are traversed by veins of quartz, granite and pegmatite.

(2) *Hornblende, gneisses, etc.*—The schistose biotite-gneisses are succeeded by hornblende gneisses, quartizites, quartz-schists, talc-schists, chlorite-schists and magnetite-quartz-schists. Many of the hill masses like the Kanjamalai, Godumalai, Chitteri, Malrayan and parts of the others are composed of these rocks.

These different rock types are frequently well foliated. The hornblende rocks are sometimes associated with much garnet, forming garnet-amphibolites as at the foot of the Kanjamalai. These rocks have been subjected to severe compression and folding and the hills are the denuded remnants of the folded strata.

(3) Some bands of *amphibolites and pyroxenites* have been *noticed in* association with the abovementioned rocks, specially in the area south of Namakkal. They may probably be younger than the gneisses.

(4) *Charnockites.*—The Shevaroys, Bodamalai and a few other hills consist mainly of charnockites. The charnockites are generally acid to intermediate in composition and also show garnetiferous varieties and some hybrid types. They are, as a rule, well banded as can be seen along the road-cutting going up from Salem to Yercaud on the Shevaroys.

(5) *Granite and Pegmatites.*—Granites and associated pegmatites which are very prominent in the northern parts of Salem, are represented in these areas by intrusive bosses amidst the older rocks. Graphic granites are noticed at the western end

of the anjamalai, on both the flanks of the Godumalai and on the Talamalai and Tirthamalai. Pegmatite and quartz veins are quite common.

(6) *Ultrabasic rocks.*—Ultrabasic rocks like periodotites and dunites which occur in this district are probably younger than the granites. They have suffered some alteration (e.g., the formation of magnesite) but have not been folded or disturbed. Their precise age in relation to the granites can be settled only after detailed mapping.

(7) *Dyke rocks.*—Basic dykes, mainly doleritic in texture and composition, are fairly common in the areas under consideration. As they cut across the other formations, they are considered to be the youngest.

Strike directions.—North of the Attur valley the rocks have a north-east to south-west trend. They run east to west in that valley and its immediate neighbourhood. The rocks of the Chitteri and Kalrayan hills have a north-east to south-west strike while parts of the Tirthamalai show the presence of north to south strike. In the Kollimalai, south of the Attur valley, the trend is generally north-east to south-west, but all the hills south of Namakkal, including the Talamalai exhibit a nearly east to west strike.

V.—DESCRIPTION OF THE DEPOSITS.

For purposes of description, the iron ore deposits will be taken up in the following order:—

(1) Kanjamalai.

(2) Attur valley Godumalai; area north-east and south of Godumalai; Vellalakundam hills including Perumamalai; Singipuram and Puduppalayaiyam hills.

(3) Attur area—Tammampatti; Singiliyankombai.

(4) Tainandamalai and Chitteri hills—Belur and Sittilingi.

(5) Thirthamalai.

(6) Area between Namakkal and Rasipur.

(7) Kollaimalai.

(8) Pachchaimalai and its spurs.

1. *Kanjamalai* (11° 378: 78° 3′ 30″) (*Plate* 1).

General.—The Kanjamalai (possibly derived from 'Kantamalai' meaning a hill of lodestone) is a prominent hill about 4 miles west-south-west of Salem town. The broad gauge main line of the South Indian Railway runs a short distance south of the hill, and the railway station of Virapandi road (formerly known as Ariyanur) is just over half a mile from the foot of the hill.

The plan of the hill is roughly oval in outline. It measures 4½ miles in an east to west direction and 2½ miles north to south. The central ridge of the hill rises well above 2,000 feet from the foot, the highest point having an altitude of 3,236 feet.

Near Sidharkovil on the west, the hill sends out an off-shoot which looks almost completely isolated from it. Both the northern and southern flanks are steep, the former being the steeper. They are cut up by numerous gullies but only a few of them contain water. There are two perennial springs on the western flank, one near Sidharkovil and the other near Sevampalaiyam. The hill is devoid of trees except a few in the gullies, and is covered by thorny shrub.

Structure.—The hill has a basin-shaped structure as already observed by Kind and Foote. The average dip is about 55° but on the northern side it may be anything from 50° upwards. The long axis of the structure lies just north of the ridge at the top of the hill. The dip is eastward on its wetsern side, while in the ridge marked 1992 south of Sidharkovil, the dip averages north-east, deviating a few degrees from that direction.

A generalized section of the Kanjamalai shows the following succession (*see* section, Plate II):—

(*a*) Light coloured flaggy gneiss, with or without garnet (Base of hill).

(*b*) Talcose schist.

(*c*) Magnetite-quartizite (Band I).

(*d*) Massive garnet-amphibole gneiss.

(*e*) Alternating hornblendic and felspathic gneisses.

(*f*) Magnetite-quartzite (Band II).

(*g*) Massive garnet-amphibole rock.

(*h*) Magnetite-quartzite (Band III).

(*i*) Flaggy light coloured gneiss.

(*j*) Garnet-amphibole gneiss, sometimes with quartz (summit of hill).

(*a*) This is a light coloured, fine grained flaggyrock frequently showing garnet. Occasional biotite may be present. This rock is prominently exposed on the southern side dipping at an angle of 60° to 70° towards the north. In places it becomes a coarse garnetiferous gneiss. Slabs of these stones are locally used for paving.

(*b*) The talcose schist does not form a persistent band but is seen on the eastern, southwestern and western parts of the hill. In places it is associated with chlorite and actinolite.

(*c*) Described later.

(*d*), (*g*) & (*j*) This rock has a pepper and salt appearance from a distance and seems to form perhaps a fourth to a third of the total mass of the hill. Similar rock is seen also in the long ridge that runs north-east of Kanjamalai and in the hillocks, east of Sidharkovil. This can be seen prominently on the southern flank of the Kanjamalai as two parallel ridges, which are about 100 to 150 feet thick in the east but become gradually thicker to the west. A comparatively thin band is noticed at the southern base of peak 1992 but this becomes thick near Sidharkovil.

The rock is composed of green pleochroic amphibole (apparently hornblende) and the ordinary type of garnet, the latter sometimes measuring 5 or 6 inches across but always much cracked.

(*e*) *Hornblende and felspathic gneisses.*—These are flaggy and break up into comparatively thin slabs. When rich in felspar they are light coloured. Generally they appear somewhat banded. They are well exposed on the northern flank of the hill.

(*i*) *Light coloured gneisses.*—These are somewhat similar to the gneisses mentioned under (*e*), but occur between Band III of the magetitie-quartzite and the summit ridge.

Intrusive rocks.—A pink *granite* (grading into graphic granite) with bluish quartz occurs as an intrusive at the base of the peak ·1992 above the northern bifurcation of the first band of magnetite-quartzite. This granite has also been observed in the valley east of Siddharkovil, south of Tambatulipatti village and in the open valley around the Kanjamalai. In a few places this granite has been found to be interbanded with the gneisses. A large number of quarty *veins* also traverse the gneisses some being of good thickness. They are well seen in the south-western part of the hill and near Sidharkovil.

At the north-east corner of the valley east of Sidharkovil a large patch of *dunite* with thin magnesite veins can be seen. A little chromite is asociated with this.

A dyke of delerite crosses the eastern end of Kanjamalai. It can be seen half a mile south-east of Perumampatti and at the south-eastern end of the Kanjamalai above the temple.

The above description applies to the general succession of rock formations in the Kanjamalai. Below is given the succession seen at the south-eastern end of the hill, in which some variations will be noted. The rocks from below upwards are—

	FEET.
(*a*) Light coloured flaggy gneisses with muscovite and biotite	30
(*b*) Partly schistose greenish rock (much amphibole)	50
(*c*) Iron ore band I (A)	60
(*d*) Amphibole schist (much actinolitte)	150
(*e*) Mica-quartz gneiss with some felspar (and sillimanite)	100
(*f*) Amphibole schist	230
(*g*) Amphibole-quartz gneiss	50
(*h*) Pyroxenite altered to amphibolite	50
(*i*) Garnetiferous gneiss (garnet, quartz, felspar) ...	200
(*j*) Amphibolite (amphibole, pyroxene felspar).	320
(*k*) Felspathic gneiss with much quartz	300
(*l*) Iron ore band II (B)	40
(*m*) Hornblende gneiss	100
(*n*) Iron ore band III (C)	40
(*o*) Fine grained granitic gneiss	60
(*p*) Garnet amphibolite (top ridge)	50

Magnetite-quartzite.—There are three main bands of magnetite-quartz rock which, because of the basin-shaped structure, form concentric elliptical rings. At the western end of the hill there are some minor bands formed probably as a result of the splitting up of the main bands. These, however, are not of much importance as they are of limited size. A description of the bands follows.

Band ' A '.—The lowest band may, for purposes of description, be designated Band A. It forms a continuous ring around the hill except for the fact that its continuity is broken at the eastern and western ends of the hill. At the eastern end, the two disconnected ends may be seen running into the grove of palmyra palms as two parallel reefs.

This band is seen as a series of arched outcrops on the northern and southern flanks, forming the crests of small knolls 100 to 300 feet in height, separated by valleys or depressions through which streamlets flow out of the hill sides. When followed westward from the palmyra grove on the southern side of the hill, the band is seen as a dark ridge with an average thickness of 30 feet. Here it is fine-grained and contains some ferro-magnesian minerals. Further west the band is about 45 feet thick, while west of the temple, in the stream section, it is more than 100 feet across. It then becomes thinner and, in the third stream section west of the temple, the average thickness is 35 feet and the rock is gneissic and of rather coarse grain with ' auger ' shaped magnetite. Associated with this is a thin band of amphibolite. Just at the eastern end of the large gap through which issues a perennial spring, the ore band is 30 feet thick, greenish grey in colour and contains much amphibole.

There is no outcrop of this band for 100 yards west of the spring. In the centre of the gap, amidst the thorny shrubs, two short parallel outropcs of magnetite-quartz-rocks are met with, one being 20 feet thick and the other about 10 feet. On the knoll west of the gap, it appears to be folded and shows three bands. The northern one is 30 feet thick and gneissic in appearance with a high content of magnetite. The central one is much weathered and associated with a bed of amphibolite; it is about 20 feet thick and appears to have been sampled extensively as there are several (pits in it. The southern one is about 40 feet thick and contains large bebs of magnetite; it contains a 2-foot layer of magnetite exhibiting the property of natural magnet (lodestone). The northern and southern bands continue westwards and are seen in the seventh stream section where their total thickness is 55 feet and the rock contains some ferro-magnesian minerals.

At the eighth stream the branches unite again into one band having a thickness of over 30 feet. In the ninth and tenth streams the thickness is around 50 feet and the material granular in texture. The band then bifurcates near the eleventh stream section, the upper part being 10 feet thick and the lower 40 feet, separated by gneissic rock. The upper band gradually becomes thicker up to the scrap south of point ·1992, while the lower one thins out and disappears near the spring. The upper band

veers round the peak ·1992 (band Ab) at a height of about 700 feet above the plains and disappears on the western side of that peak. A small outcrop of the Band ' A ' is seen along the foot-path from Ilampillai to Sidharkovil just north of hill ·1992.

Band ' A ' disappears from the abovementioned place for nearly two miles on the northern side of the Kanjamalai. It is again seen as a thin band about a mile east of the eighth mile stone on the Salem-Ilampillai Road. Here it is nearly two miles on the northern side of the Kanjamalai rock. It can then be seen in a series of knolls, going towards the east. On this side also, there is a valley between this band and the main hill. Just south of Tumbatulipatti the band bifurcates, the total thickness being 80 feet. South of Perumampatti it has a lenticular shape with gneissic interculations which split it up into four separate layers. The aggregate thickness of these layers of magnetite-quartzite will be about 150 feet and the material fairly rich in magnetite. There are two temples east of this place, marked on the map by two dark squares. East of these temples, the minor bands again coalesce into one of 40 feet thickness. Then it bifurcates south of peak ·1919 the two branches continuing eastwards down to the plains, with thickness of 20 feet and 30 feet respectively. Below and parallel to these, there is a third thin band.

The total length of Band A is nearly ten miles and its average thickness 60 feet. It dips into the hill (from all sides) at an angle of 50°—60°.

Band ' B '.—The second band of magnetite-quartz rock is found some distance up the flank of the hill. It also encircles the hill except for a short gap on the southern slope. It may roughly be taken as running at a height of about 1,000 feet above Band ' A ', though it goes further up in the western part of the hill.

Starting from near the peak ·2201 at the eastern end, the Band ' B ' can be seen at an altitude of 1,950 feet just below that peak. Its thickness here is about 40 feet and the rock is coarse and banded. Continued westward, it improves in thickness but has a weathered appearance and contains a fair proportion of hematite. It is exposed as a series of arched ridges up to the fifth stream. Though it is not well seen for some distance beyond here, it undoubtedly continued underneath the talus. In the gorge south of the first ' A ' of the word *panchayat* on the map, its thickness is barely 20 feet but it rapidly climbs of the contour to a higher level. Further west, about thirteenth stream section, it bifurcates, one branch running at about 2,000 feet contour and the other at 2,250 feet, each having a thickness of 30 feet. They then descent into the valley east of Sidharkovil and veer round to the northern side of the hill. The lower branch disappears near the stream which runs into the bank of Ariyakavundanpatti. The higher one continues eastwards at about 1,800 feet contour with an average thickness of 35 feet and dipping at an angle of 60°. This band is more weathered than the other and contains more hematite.

The total length of the Band 'B' is estimated to be about six miles and its average thickness 30 feet.

Band 'C'.—The third band (B and C) runs parallel to and above the Band B. Except for a gap in the north-western part of the hill, the outcrop of this band makes a complete ellipse. It caps the peak ·2201 at the eastern extremity of the hill. It is well exposed on the southern flank, west of the temple, where it is coarse grained, banded in structure and has a thickness of 30 feet. Further west, it runs parallel to Band 'B' at an altitude of 2,000 feet, where it has about the same thickness. It runs on to east of Sidharkovil and ends on a conical spur. Here the band is 50 feet thick, coarse in texture and with fairly good magnetite content. It is not visible at the western end of the northern flank for about a mile and a half. It is seen again south of Tambatulipatti and 100 feet about the Band 'B'. The average thickness of the band in the eastern part of the northern flank is 30 feet. The total length of the band is about six miles and the average thickness 30 feet.

Minor bands.—There are a few extra bands in the neighbourhood of the peak ·1992. The top of this is made up of magnetite-quartzite and on the southern scarp its thickness is around 70 feet. North of point ·1992 there are three bands running east-west with a northerly dip. They are separated from each other by gneisses. The upper one is 600 feet in length and 20 feet thick; the middle one 600 feet long and 15 feet wide; the lower one nearly half mile long and 60 feet thick on an average, though the magnetite content is rather low.

There are also four short bands where the letters "NJ" of "Kanjamalai" are printed on the map, i.e., east of peak ·1992. These bands are parallel to each other. They measure, from the lowermost to the uppermost, 10 feet, 10 feet, 25 feet and 30 feet respectively. Their lengths could not be measured on the ground as they are covered by thorny shrubs and are in part inaccessible.

Estimate of ore reserves.—The structure of the Kanjamalai suggests that the ore bands form an elongated basin-shaped structure and we may therefore expect the outcrops on the flanks to be connected with each other underneath. The ore bodies are undoubtedly beds of sedimentary origin. Local irregularities in thickness and magnetite content are of course to be expected.

For the purpose of calculating the reserves only a depth of 100 feet from the outcrop is taken, in the case of each band, down the dip direction. It is also assumed that ten cubic feet of ore *in situ* make up one ton.

First band (Band 'A')—

Total length	10 miles.
Average thickness	60 feet.
Depth assumed	100 feet.
Quantity of ore	$\frac{10 \times 5{,}280 \times 60 \times 100}{10}$
	=31,680,000 tons.

Second band (Band 'B')—

Total length	6 miles.
Average thickness	30 feet.
Depth taken	100 feet.
Quantity of ore	$\frac{6 \times 5,280 \times 30 \times 100}{10}$ = 9,504,000 tons.

Third band (Band 'C')—

Dimensions the same as the second band.	
Quantity of ore	9,504,000 tons.

Minor band (Band 'A')—

Total length	1 mile.
Aggregate thickness (approximate)	75 feet.
Depth taken	100 feet.
Quantity of ore	$\frac{1 \times 5280 \times 75 \times 100}{10}$ = 3,960,000 tons.

The total quantiy of ore from all the banks in the Kanjamalai, to a depth of 100 feet will be 54,648,000 tons or say 55 *million tons*.

2. *Attur Valley* (*Plate III*).

The long narrow plain extending from Salem on the west to Talaivasal on the east is commonly known as the Attur Valley as the town of Attur is located at its centre. It is 42 miles long and about eight miles wide on an average. To its north are the Shevaroys, Chitteri Hills, Kalrayan Hills, Jarugumalai and Bodamalai. To its south are the Pachaimali and Kollimalai. In the valley itself are the Godumalai and the Maliyakarai and Attur hills. As stated before, the Salem-Vriddhachalam-Cuddalore metre-gauge branch of South Indian Railway passes through this valley.

Practically all the hills except the Shevaroys are made up of gneissic and schistose rocks similar to those found in the Kanjamalai. They are all denuded remnants of folded strata. The general trend of the rocks in the valley is nearly east-west.

The chief rock types met with are gneisses including garnetferous ones, quartz schists, chloritic schists, amphibolitics and pyroxenites. Veins of granite and quartz traverse the gneisses, and schists. Basic dykes are also sometimes met with.

2-A. *Godumalai* (11° 41′: 78° 20′).

This hill is situated at a distance of 11 miles, east of Salem town. At its south-eastern foot is the railway station called Seshanchavadi. The hill is somewhat wooded. It is about four and a half miles long east to west, being narrow in the west and becoming gradually wider in the east, where it is nearly two miles broad. It shows a series of conical peaks whose altitudes also increase from west to east. The highest peaks, having altitudes of 3,179 feet and 3,188 feet, are at the eastern end of the hill.

The rocks in the hill appear to have been highly compressed for those on the two flanks dip very steeply. The axis of compression coincides with the elongation of the hill. At the north-eastern end the strike tends to become north-east. The general dip is northwards at high angles.

Both Kanjamalai and Godumalai lie more or less along the same strike, and there are also resemblances in their lithology. The succession of the formations cannot be easily made out in Godumalai because of the fairly thick vegetation and the very high dips of the rocks. The lowest beds are chloritic and hornblendic schists, well exposed at the eastern end. Above these are light coloured gneisses carrying some hornblende. These are succeeded by quartzose rocks amidst which are bands of granite. The backbone of the ridge is formed of megnetite-quartzites which are found along the entire length of the hill. At the western end only one band of magnetite-quartzite is noticeable whereas near the eastern end two bands appear to be present.

A basic dyke runs into the hill from the south. It has a width of 50 feet and a length of about a mile in the plains. A few veins of quartz are seen at the south-eastern end of the hill and also in the adjoining part of the plains. The veins are milky white in colour and free from iron in places. They are up to five feet in thickness.

Magnetite-quartzite.—The band of ore which forms the central ridge of Godumalai runs east to west for nearly three miles.

Starting from the west, the ore ridge is seen to form the conical peak ·1646, half a mile east of Sarkar Nattarmangalam. The thickness of the band near this peak is about 65 feet, though it appears broader here on account of much debris scattered about. The ore is steel grey in colour and of medium-grained texture. Associated with the ore is an amphibole which has a yellowish green colour. The ore band thins down when followed eastwards and is barely 10 feet thick in the valley east of peak ·1643. Hereabouts the ore is schistose and consists largely of hematite. Proceeding further eastwards, the ore becomes richer in magnetite again, with a change in the strike and has a thickness of 60 feet. The original direction of strike is resumed near ·1653. It then continues on to hills ·2066 and ·2546 through thick jungle, with an average thickness of 50 feet. From the last-mentioned point, the ore band stands as a vertical-sided mass resembling ruined fortress walls, 100 feet high. In this portion, much of the ore is medium to coarse grained.

The crag with point ·2894 is a prominent landmark here. It is a great precipice composed entirely of magnetite-quartz rock, which is nearly 500 feet high. The ore bed is about 60 feet thick and is coarse textured. Beyond here there are two bands in the level part of the hill top between the peaks ·3179 and ·3188. The thickness of each is 50 feet and the rock medium grained and gneissic in texture. The cliffs composed of ore in this part of the hill have a dull brown appearance but

they reflect a beautiful golden brown colour when the sunlight at dawn catches them.

On the northern slope, near the eastern extremity of the hill the iron ore bands can be traced for a length of about 100 yards, each having a thickness of 60 feet. They are not seen down the slope of the hill for a short distance, but one of the bands is again picked up at the base of the hill, having a thickness of over 60 feet. Here it contains much hematite. A little to the north-east this band becomes covered up by soil and alluvium in the plains.

***Ore reserves*—**

(*a*)	**Length of band up to cliff ·2994**	**2¾ miles.**
	Average thickness	**50 feet.**
	Depth	**100 feet.**
	Quantity	**11/4 × 5280 × 50 × 100 × 1/10. = 7,260,000 tons.**
(*b*)	**Cliff ·2294 ; Lengh .. ..**	**300 feet.**
	Thickness	**60 feet.**
	Depth	**500 feet.**
	Quantity	**$\frac{300 \times 60 \times 500}{10}$ =900,000 tons.**
(c)	**Length of two bands east of peak ·2994 .. .. ..**	**½ mile.**
	Total thickness	**100 feet.**
	Depth	**100 feet.**
	Quantity	**$\frac{2,640 \times 100 \times 100}{10}$ =2,640,000 tons.**
(*d*)	**Length of the band north on north-east lope .. ..**	**5 furlongs.**
	Average thickness	**50 feet.**
	Depth	**100 feet.**
	Quantity	**$\frac{3,300 \times 50 \times 100}{10}$ =1,650,000 tons.**

The total quantity of ore estimated in this hill to a depth of 100 feet from outcrop (except for the cliff ·2994) is 12,450,000 tons.

(*e*) *Agraharam.*—Half a mile north-east of Agraharam at the eastern end of the tank, there is a small knoll of amphibole schists over which there is a bed of iron ore, 25 feet thick. The ore contains much hematite and appears to be rather poor. It can be traced for a distance of 600 yards.

(*f*) *South-east of Agraharam.*—About half a mile south-east of Agraharam there is another band of ore which can be traced for 200 yards in a north-east-south-west direction. The ore is massive and fine grained and dips 80° towards the north. It bifurcates at its eastern end and is intercalated with quartz-schist. It is locally quarried for use as a building stone. It disappears under the soil westwards but is apparently present underneath as there is another outcrop of the same rock 100 yards away. This band is highly siliceous.

(*g*) *Sarkar Nattarmangalam.*—Just west of the footpath two furlongs west of Nattarmangalam there is an outcrop of ore which is 100 yards long. This band strikes east-north-east and dips vertically.

Half a mile east of Sarkar Nattarmangalam, near the north-western extremity of Godumalai, there is a small outcrop. It is 100 yards long and 20 feet thick and appears to be rather poor in iron.

2-B. Area north-east of Godumalai.

Though the magnetite-quartzite band of Godumalai continues north-eastwards to Belur, the outcrops are not continuous. The bands seen in this area are mentioned below:—

(1) There are four short runs of ore on hillock ·1365, north-east of Godumalai. The thickness of these bands varies between 5 and 20 feet.

(2) On the northern side of the hill, half a mile north of Kumaraswamiyur there are two parallel bands, each 10 feet thick, which are seen for some 300 yards in a north-east-south-west direction. They dip south-eastwards and the ore is comparatively rich in hematite and high in silica.

(3) On the southern slope and near the western end of hill ·1593 is a band 10–12 feet thick running on a north-east-south-west direction for a distance of about one mile. On the same side is seen another band 200 yards long. Both these bands are poor in their magnetite content.

(4) Two bands, each 150 yards in length and 10 feet in thickness, are seen at the eastern end of the hill ·1593. The ores are poor.

(5) The hill ·1307 shows two parallel bands or poor material.

(6) There is a short band, about 10 feet thick, on the Valappadi road five furlongs south of Belur. Another small outcrop is seen some 400 yards south of the abovementioned band. This also is 10 feet high.

All the bands noticed above are poor in magnetite content and have therefore not been included in the calculation of ore reserves, though portions of these will undoubtedly be amenable to magnetic concentration.

2-C. Area south of Godumalai.

South of Godumalai there are at least ten conspicuous runs of magnetite-quartzite of varying dimensions and richness. Half a mile south of Mettupatti the hill containing the points ·1480 and ·1551 is seen to be composed mainly of felspathic gneisses, pegmatities and amphibole-rocks. At the western base of this hill there is a band whose thickness shows a variation from 10 to 20 feet and which can be traced for a distance of two miles. Its continuity in the middle of the hill is broken for a few yards by a dolerite dyke.

Hills near Vellalakundam.—The hills ·2157, ·1944, ·1968 and ·1916, east of Vellalakundam, are composed of felspathic and amphibole gneisses and magnetite-quartzites, traversed by a few basic dykes in the south-eastern part.

(*a*) *Perumamalai.*—On the western flank of the conical mass of Perumamalai (·2157) there are two bands of magnetite-quartzite, one at a height of 400 feet from the base and the other further up. They have a thickness of 10 feet each. They can be followed round to the northern side of the hill where their trend is east-west and can be traced for two miles in the neighbourhood. They descend down into the plains and run, with an east-north-east to west-south-west strike, for another two miles, to within half a mile of Puduppalaiyam. In places, only one of these bands is prominent and the outcrops are not continuous. They reappear south-west of Puduppalaiyam on hill ·1500 which has a synclinal structure. The average thickness of the two bands here is 15 feet and the magnetite content richer than Perumamalai.

(*b*) There is a band about 3 furlongs long and 15 feet thick, east of hill ·1944. It has an east to west strike and southerly dip. Its average thickness is 15 feet and the magnetite content poor.

(*c*) A little to the south of the above is another band, running east to west for nearly a mile with a thickness of 10 feet. It is also poor in magnetite.

(*d*) South of the above, there is another band having a total length of four miles and a thickness of 10 to 20 feet. For about two and a half miles it has an east to west strike and thereafter an east-north-east to west-south-west strike. For a mile and a half from its western end its thickness is 10 feet and the magnetite content poor. Where the band traverses the valley between the hills ·1968 and ·1944, it contains an one-foot thick layer of magnetite having the property of lodestone. The thickness of the ore band increases to 30 feet on the spur north of ·1968. It then cuts the northern end of hill ·1968 with an average thickness of 20 feet and disappears about one and a quarter miles west of Singipuram, after crossing a stream here. It probably continues underneath the soil as its continuation is apparently seen on hill·1700 south-east of Valappadi.

(*e*) *Hill* ·1968.—On the ridge hill ·1968 west of Ponnarampatti there is a band of magnetite-quartzite, striking in a north-east to south-west direction for about a mile and a half. The outcrop is barely 5 feet thick at the north-eastern end of the hill, but on following it up the hill the thickness improves to 30 feet. Here the dip is 45° towards the north-west and the ore is fairly rich. The band splits up into two at the top, separated by a layer of amphibole gneiss. These descend into the valley one mile east of ·1372. The average thickness of the band over its full length may be taken as 20 feet and the quality fairly good.

(*f*) Running parallel to and south of band (*e*), there is another situated on the southern flank of hill ·1968. It is 5

furlongs in length and 20 feet thick at the eastern end but becomes thinner when followed westwards. The quality of the ore is poor.

(*g*) On the hill spur south of band (*f*), there is another band having a length of two furlongs. It is 40 feet thick and contorted here and there.

(*h*) Overlying the felspathic and amphibole gneisses west of Ponnarampatti, there is a band which is the easternmost on the hill ·1968. It is more or less parallel to the other bands and has a length of one mile and a thickness of 15 feet. The iron content of this band is poor.

It may be mentioned in passing that, 50 feet above this band, there are gneisses containing flakes of graphite which are however not abundant.

(*i*) *Hill* ·1916.—This is the southernmost hill of the Vellalakundam group and lies one and a half miles north-east of Veppilaipatti village. A band of magnetite-quartzite runs east to west from the top of this hill for a distance of three miles and dips southward. The eastern half of the band is about 20 feet thick while the western half consists of two branches of which the southern is 70 feet thick and the northern 20 feet thick. The magnetite content is, however, very poor.

On the southern flank of this hill there is a band two furlongs long and 10 feet thick, trending east to west. It is quite poor as ore. There is a graphite-bearing gneiss below it.

2-*D*. *Singipuram Hill* (·1373).

About two and a half miles south of Valappadi and just west of Singipuram village, there is a small but prominent hill. It has an isoclinal structure, all the beds dipping northward. The hill is three furlongs long in the strike direction (east-north-east to west-south-west).

On the southern flank the lowest member is a graphic granite. Above it is a 20-feet layer of amphibolite. This is succeeded by a very siliceous magnetite-quartzite band, 5 feet thick. Above this are an amphibole-gneiss (30 feet), a second band of magnetite-quartzite (8 feet), granitic gneiss and a third band of magnetite-quartzite (10 feet). The last-mentioned band occupies the top ridge. On the northern slope also there are two bands of magnetite-quartz rock, each 20 feet thick.

The magnetite-quartzite bands appear to be parallel to each other. They are exposed over a length of three furlongs and the aggregate thickness of all the bands is about 60 feet. They appear to continue, beneath the alluvium of the plains, into the bands in the hills further west.

2-*E*. *Pudupalaiyam*.

The band referred to here appears to be the continuation of that on hill ·1500 south-west of Pudupalayam. It crosses the Valappadi-Singipuram road near the tank about three furlongs

south-east of Pudupalaiyam. It extends in an east-north-east—west-south-west direction for a mile and dips at 30° towards the south-south-east. The band is not fully exposed all through its length, and though its thickness is over 60 feet in places, the average may be taken as 30 feet. The ore is good in one or two places east of the village but not throughout the length of the band.

Parallel to and half a mile south of the above band, there is another having a length of two furlongs and a thickness of 10 feet. The proportion of ore in this is poor.

There are two bands on hill ·1170, one mile south-east of Chinna Krishnapuram. One of these is on the top and the other at the north-west corner of the hill. The first band can be seen for three furlongs in an east-north-east—west-south-west direction with an average thickness of 10 feet. The second is only 100 yards long and 10 feet thick. Both the hands are highly siliceous.

Karadipatti.—Half a mile south of Karadipatti there is a run of magnetite-quartzite which is two furlongs long and 15 feet thick on an average. It is also very high in silica.

Ore reserve in the area south of Godumalai.—In calculating the ore reserves, only those bands which appear to be fairly rich in magnetite content are included. The others have been left out, though they may be of fair quality in parts. The estimates therefore err well on the conservative side.

Perumamalai—

			TONS.
(*a*)	$\frac{4 \times 5,280 \times 10 \times 100 \times 2}{10}$	=	4,224,000
(*b*) Eastern half	$\frac{3}{2} \times \frac{5,280 \times 30 \times 100}{10}$	=	2.376,000
(*e*)	$\frac{3}{2} \times \frac{5,280 \times 20 \times 100}{10}$	=	1,584,000
(*f*)	$\frac{5 \times 660 \times 20 \times 100}{10}$	=	660,000
(*g*)	$\frac{3 \times 660 \times 40 \times 100}{10}$	=	792,000
Pudupalayam (estern half.)	$\frac{1}{2} \times \frac{5,280 \times 30 \times 100}{10}$	=	792,000
The total in the area will be ..			10,428,000

3. *Attur area.*

There are several hills in the Attur valley between the Kalrayan and Kollaimalai hills, ranging in altitude between 1,000 feet and 2,000 feet. They have generally an east-west strike, the dip being to the north or south. They consist mostly of felspathic gneisses and amphibole rocks, with occasional reefs of magnetite-quartzite.

3-*A*. *South-west of Attur.*

Three miles south-west of Attur a band of magnetite-quartzite is seen on the northern flank of hill ·2013, dipping into the hill. It has an east-west trend and a length of nearly 1¼ miles.

To the west it trends in a south-west direction. It is observed on the top of the hillock on the path of Murugam village and can be traced from there for about half a mile in a southerly direction. It is fairly rich in magnetite and the average thickness is around 25 feet.

Ramanayakkanpalaiyam.—At the foot of the Kalrayan hills north of Ramanayakkanpalaiyam there is a band of ore half a mile in length and 40 feet thick. Its full extent is obscured by jungle. The magnetite content of this is rather low.

The ore reserve in the Attur area is—

$$\frac{3}{2} \times \frac{5,280 \times 25 \times 100}{10} = 1,980,090 \text{ tons.}$$

3-*B*. *Thammampatti area.*

South of the Attur valley there is a minor valley around the village of Thammampatti, between the Paiturmalai, Kollaimalai and Pachchaimalai. It is irrigated by the Sweta Nadi. Thammampatti is connected by good roads with Turaiyur and Attur. The rocks here are the gneisses with a general east-west strike and southerly dip.

(*a*) Running east-west, on hill ·1196 about a mile north-north-west of Thammampatti, there is a band of poor quality ore. It is about 20 feet thick.

(*b*) Near Ulipuram, extending on either side of the villages of Ulipuram in an east-north-east—west-south-west direction for a total length of four miles, there is a band of magnetite-quartzite. The eastern part is half a mile east of the village and extends for nearly three furlongs with an average thickness of 30 feet and a steep dip to the south-south-east. Between this and the western part, it is covered for some distance. West of Ulipuram the band is nearly three miles long and is well exposed on the southern slopes of hills ·1551 and ·1691. The average thickness of this part is also 30 feet. The portion which passes between the hill ·1705 and the one south of it is thinner, and it dies out further west. The magnetite content is in general rather poor.

(*c*) There are two hills (·1668 and the one to its west) a mile south-east of Nagaiyampatti. On their south side is an ore band running for ¾ mile in an east-west direction. The average thickness is 20 feet and the magnetite content poor.

(*d*) The hill ·1717 south-east of Sendarapatti is made up of amphibolites and related rocks. They have a high southerly dip. On the southern flank of the hill there is an ore band 10 feet thick, parallel to the general strike, but of poor quality.

After an interval, this band can be picked up to the east on the northern slopes of the hills ·1295 and ·1357 near Palacolu. It has a length of one mile and a thickness of 20 feet. The average ore is rather poor but there is some high grade " float " weathered out of the rock. The weathered material must have been extensively used by indegenous smelters in centuries gone by since there are slag heaps (and pieces of broken crucibles), scattered over a distance of three to four furlongs close to the bed of ore.

(*e*) The hill ·1093 one mile west-south-west of Sendarappatti shows four short bands of ore trending east-north-east—west-south-west each being 10 to 12 feet thick. The central ridge of the hill consists of a band 50 feet thick and 300 feet long. The other bands are 50 to 200 yards long. The average length of the bands may be taken as 100 yards and the aggregate thickness about 70 feet.

Ore reserves—

			TONS.
Band (*c*)	$\frac{3}{4} \times \frac{5,280 \times 20 \times 100}{10}$	=	**792,000**
Part of band (*d*)	$\frac{5,280 \times 20 \times 100}{10}$		**1,056,000**
Band (*e*)	$\frac{4 \times 300 \times 70 \times 100}{10}$	=	**840,000**
			2,688,000

3-*C*. *Singiliankombai.*

(*a*) Running through the small hill half a mile south of Singiliyankombai there is a band having a length of 500 feet and a thickness of 12 feet. The quality of the ore is fair.

(*b*) About a mile south of this village and just south of the hills ·2194 and ·1536 there is a band running east-west for nearly two miles. The average thickness is 50 feet and the quality of ore is fair.

(*c*) Half a mile north of Singiliyankombai is another band going over hill ·1706. It runs north-east—south-west for a mile, with a thickness of 25 feet.

(*d*) *Malliyakkarai.*—A mile to north-east of Ichchampatti and at a southern foot of the hill ·1516 is a band half a mile long and 15 feet thick. The band is not fully exposed as it is in a low-lying area and is partly obscured by soil.

Ore reserves—

			TONS.
(*a*)	$\frac{500 \times 12 \times 100}{10}$	=	**60,000**
(*b*)	$\frac{2 \times 5,280 \times 50 \times 100}{10}$	=	**5,280,000**

Ore reserves—cont.

			TONS.
(c)	$\frac{5,280 \times 25 \times 100}{10}$	=	1,320,000
(d)	$\frac{1}{2} \times \frac{5,280 \times 15 \times 100}{10}$	=	396,000
			7,056,000

4. *Tainandamalai and Chitteri Hills* (See *Plate IV*).

The Chitteri hills lie to the east of the Shevaroys and have a length of 25 miles in a north-east—south-west direction with Belur to their south and Kottappatti to their north. They are separated from the Kalrayan hills, which lies on their east, by the Tumbal pass. They comprise a number of hills which rise to a height of 1,000 to 2,000 feet above the surrounding plains. They are clothed with fairly good forests.

The rock forming these hills are similar to those in the Godumalai and include gneisses, amphibolites, hornblende chlorite and talcose schists and magnetite-quartzites. These are intruded by granite and pegmatite and basic dykes. The strike varies from north-east—west-south (in the southern parts to north-east—south-south-west (in the northern parts) and the dips are steep towards the north-west.

4-A. *Belur area.*

(*a*) This band can be seen near the temple on the road to Kurichi, where it is 40 feet thick. The general trend indicates that it may be the continuation of the Godumalai band. It then ascends up the western flank of hill ·1609, but it is obscured for a short distance near that peak. The band is continued to the north-east and is well exposed in the next peak. Beyond this it splits up into two branches, one 10 feet and the other 40 feet thick, and the ore contains much hematite in addition to the magnetite. One of these branches dies out and the other continues to east of Kurichchi and into the Kanakanur valley where it is 15 feet thick. It continues for a further half a mile to the north-east. The total length of the band is 2½ miles with an average thickness of 30 feet, the quality of the ore being fair.

(*b*) Parallel to and about a mile east of the above, there is a band which can be seen in the stream issuing from hill ·1941 about 1½ miles east of Andiyur. This is its western end. It continues in a north-easterly direction for 100 yards and is obscured by soil but can be picked up again at the foot of the hill to the north-east where it is 20 feet thick. It crosses the western part of the top of hill ·2009 and goes into the valley west of Idaiyapatti as a prominent reef 40 feet thick. It then passes half a mile east of Neyyamalai amidst thick jungle, being 30 feet thick here. It turns more towards the east from here passing through the hill ·2301 south of the Alangadi hamlet. Beyond

this it is much obscured by jungle though lumps of magnetite in the testify to the continuation of the band to some distance east of Govindankadai.

The total length of this band is nine miles and the average thickness about 30 feet. The magnetite content is around 50 to 60 per cent.

(*c*) This band is parallel to and about half a mile east of (*b*) and runs in a north-east—south-west direction for nine miles. The greater part of it is covered by jungle and rock debris and in one or two places west of Tumbal, it contains occasional crystals of pyrite. The average thickness may be taken as 30 feet (variation from 15 to 40 feet) and the magnetite content as around 50 per cent.

(*d*) This is well seen about two miles west of Idaiyapatti and can be observed over a distance of four miles through the hills ·2009, ·1304, ·2360 to the east of and parallel to the bands described above. Its thickness in the hill ·2009 is 25 feet. It is lost to view beyond the hill ·1614, a mile north-west of Tumbal. Where it is not clearly exposed, its presence is indicated by the scattered boulders of magnetite.

The avearge thicknesss is around 25 feet and the magnetite content about 35 per cent.

(*e*) This is futher east of the above and has a length of three miles. It is seen in the south-west at a locality one mile north-west of Vellalapatti and cuts through the hills ·1592 and ·1304. It is 35 miles thick on an average and is rather poor in magnetite.

A smaller band is found east of the above, especially in the stream west of Idaiyapatti. It is about a mile long and 10 feet thick.

Finally there are a few small and thin beds in the valley west of Idaiyappatti. Their thickness are up to 10 feet. But they are all poor in magnetite content.

4-*B*. *Sittilingi area*.

The rocks of this area include the usual types met with elsewhere—foliated and banded gneisses, amphibolites, chlorite and talc achists and intrusive granite, pegmatite and basic dykes. A bed of greenish quartzite is also seen about two miles west of Sittilingi.

(*f*) A band of magnetite-quartzite is seen about a mile and quarter west-north-west of Sittilingi and east of hill ·2016. It is half a mile in length (north-east—south-west) and at least 70 feet thick, though the full thickness is obscured by debris and soil. The ore is fairly rich and contains a small proportion of hematite.

(*g*) About two furlongs west of Malatangi is another band of ore observed for a length of 200 yards in a north-east—south-west direction. In all probability it continues in a north-easterly direction under a cover of soil. The thickness of the observed portion is about 40 feet and the ore content good.

(*h*) *Suriyagadai-Kattirippatti.*—This band is six miles long (north-east—south-west) and its south-western end is half a mile north-east of Suriyagadai Forest Rest House. It is indistinct for some distance but well seen again half a mile east of Tekkalpatti in the thick jungle, where it is 30 feet thick. Further north-east it is exposed in the stream, west of Talikatimalai (·3105). Here its thickness is 30 feet and the magnetite content good. From here for two miles the band is not very clearly exposed because of heavy jungle and debris-covered outcrops. East of Puduvalaru it is seen for two miles along the same strike. The average thickness of the band may be taken as 40 feet.

***Ore reserves*—**

		TONS.
(*a*)	$\frac{5}{2} \times \frac{5,280 \times 30 \times 100}{10} =$	3,960,000
(*b*)	$\frac{9 \times 5,280 \times 30 \times 100}{10} =$	14,256,000
(*c*)	$\frac{9 \times 5,280 \times 30 \times 100}{10} =$	14,256,000
(*d*)	$\frac{2 \times 5,280 \times 25 \times 100}{10} =$	2,640,000
(*e*)	$\frac{3 \times 5,280 \times 35 \times 100}{10} =$	5,544,000
(*f*)	$\frac{1}{2} \times \frac{5,280 \times 70 \times 100}{10} =$	1,848,000
(*g*)	$\frac{600 \times 40 \times 100}{10} =$	240,000
(*h*)	$\frac{6 \times 5,280 \times 40 \times 100}{10} =$	12,672,000
	Total ..	55,416,000

5. *Thirthamalai* (See *Plate V*).

The Thirthamalai and associated hills are geographically the northern extension of the Chitteri and Kottappatti hills. The general trend of the hills as well as the direction of strike of the rocks is north-south, but near the Ponnaiyar river the strike is more nearly north-east. The dip is very steep to the west or often vertical. The rocks are of the usual types seen elsewhere in the region. The area is well wooden and most of it is a reserved forest.

Thirthamalai is about 14 miles east of Morappur railway station. The Salem-Tiruppattur road passes three miles west of this hill. Its chief peak ·3220 is composed of hard resistant magnetite-quartzites. There are four bands of magnetite-quartzites on this hill separated by gneisses and other rocks. These bands are designated, a, b, c, d, with the prefix **T** to indicate Tirthamalai.

First band (T-a).—This band is noticed on the western slope of the hill, two furlongs south-west of peak ·3220. It is about 70–80 feet thick here. It runs northwards for two miles up to the Kottappatti road but it is partly obscured by jungle and debris. It is very clearly seen along the path leading up to the temple on the hills, and in this exposure the thickness appears to be as much as 400 feet. North of the road, the band is not seen for nearly a mile but it reappears on hill ·1330 half a mile east of the hamlet of Kattavirichchampatti in the Puduvampatti reserved forest. Hereabouts its thickness is 30–35 feet. From here the band takes a north-north-east course for about four miles, passing between the deserted hamlet Kadamanpatti and the hill ·1863. The band crosses the Ponnaiyar a mile east of Ettipatti and passes into the Elavambadi reserved forest in the Uttangarai taluk. The total length is nearly seven miles. For purposes of calculation of the reserves a two mile length of the band south of the road is taken as having a thickness of 150 feet and a four-mile length with a thickness of 35 feet.

Second band (T-b).—This lies a short distance east of band T-*a* and has a length of nearly six miles. It forms the peak ·3220 and the conspicuous ridge of the hill. From its southern end on the southern slopes of Tirthamalai it runs parallel to the first band like a ridge 150 feet high and 50 feet thick. The two bands are here separated by granite. At about a mile north from its southern end, several spring issue from near the base of this band where there is a Siva temple. (It is because of these springs that the hill has received the name of *Tirthamalai.*) North of the temple the band becomes less prominent and can be followed up to the road as a low ridge. North of this road it is not seen for nearly a mile. It can be picked up again east of point ·1330, about five furlongs east of Kattavirichchampatti, where it is 35 feet thick. From here it takes a north-easterly trend and can be followed for a mile and half to west of the deserted site of Ramapuram. No outcrop is seen beyond this for a mile, after which again the band is noticed (six furlongs east of Kadambatti) and can be followed up to and beyond the Ponnaiyar river two furlongs east of Tumbal. It may continue into the Ravanvadi reserved forest but this has not been confirmed.

The average thickness of the band from the southern end to the road is 100 feet and beyond it to the Ponnaiyar about 35 feet.

Third band (T-c).—This appears to be merely an offshoot of second band and runs as a prominent ridge north-north-east from peak ·3220 for over half a mile. It reaches a maximum thickness of 100 feet and has not been seen near or beyond the road.

Fourth band (T-d).—This is seen at the south-eastern base of Tirthamalai, half a mile south of Andiyur. It can be traced in the thick jungle for a distance of two furlongs southwards. The thickness is 100 feet though it is obscured here and there by debris

Modukuli.—About a mile north-east of Modukuli is a bed of magnetite-quartzite running north-east—south-west for a distance of six furlongs and having a thickness of 30 feet.

Another outcrop occurs along the same strike about a mile north-east of Alambadi, with the same dimensions as noted above.

Ore reserves—

			TONS.
Band T-a ..	$\frac{2 \times 5{,}280 \times 150 \times 100}{10}$	=	**15,840,000**
Band T-a (northern part).	$\frac{4 \times 5{,}280 \times 35 \times 100}{10}$	=	**7,392,000**
Band T-b ..	$\frac{2 \times 5{,}280 \times 100 \times 100}{10}$	=	**10,560,000**
Band T-d (northern part).	$\frac{4 \times 5{,}280 \times 35 \times 100}{10}$	=	**7,392,000**
Band T-c ..	$\frac{1}{2} \times \frac{5{,}280 \times 100 \times 100}{10}$	=	**2,640,000**
Band T-b ..	$\frac{2 \times 660 \times 100 \times 100}{100}$	=	**1,320,000**
Modukuli ..	$2 \times \frac{3}{4} \times \frac{5\ 280 \times 30 \times 100}{10}$	=	**2,376,000**
	Total reserves ..		**47,520,000**

6. *Area between Rasipur and Namakkal* (see *Plate VI*).

The area between Rasipur and Namakkal is a plain studded with a few hills amongst which the Alvoy and Ninarmalai deserve mention. The others are low ridges having a general trend of east-north-east—west-south-west and heights of less than 500 feet above the plains. They are all denuded remnant of folds. The following bands of magnetite-quartzite have been observed in this area:—

(*a*) *Pattanam.*—There are two bands on the hill ·1040 (possibly two arms of a folded band) running east-west for a total length of four furlongs. The thickness varies from 10 to 30 feet. The southern band appears to pass eastward into a garnetiferous quartzite with practically no magnetite. The total average thickness of the two bands together is 40 feet. They are too poor in iron content to be regarded as workable ore.

(*b*) *Puduchchattram.*—The hillock ·940 (with a temple on top) about a mile north-east of Puduchchattram contains some magnetite-quartzite intercalated with other rocks and dipping steeply to the south-south-east.

At the western end of the hillock there is a rusty brown band running for a furlong along the strike up to the top (temple). It is 40 feet thick. Parallel to this, on the northern flank is another band, 25 feet thick. Between these two there are two short bands, each 100 yards long and about 10 feet thick. The two main bands are intersected by a basic dyke and reappear on hill ·768, beyond which they are not seen for a mile. They are again seen east of Ramanayakkampatti as a single band containing for half a mile, with a thickness of 50 feet. These bands are all too poor to be included as ore.

(c) *Belukkurichchi.*—A bed of magnetite-quartzite, nearly nine miles in length, runs from Makkalpudur in the south-west to Belukkurichchi in the north-east. The eastern end forms the ridge on hill. ·1500, half a mile north-east of Belukkurichchi. Near the Rasipur road, at the eastern extremity of the band, this is seen to dip 70° to the south-south-east and to have a thickness of 30 feet. On the hill ·500, there is really a double band, the northern one being 10 feet thick and the southern one 80 feet; the two units, when followed westwards into one band having a thickness of 50 feet. Here the ore is partly hematitic. The band gradually thins down and disappears near the tank at Idaiyappatti for about half a mile up to the neighbourhood of Kunjanur. It reappears on the high ground north of Tammanayakkanur with a thickness of 40 feet and with a steep-south-south-east dip. After a distance of about a mile it is again obscured by soil, but reappears half a mile north of Karakurichchi (·706). At this place the band is 15 feet thick. Between here and the Namakkal-Salem road the presence of the band is indicated by boulders and lumps in the cultivated fields. It is again well exposed on hill ·719 near mile 21–7 of the above-mentioned road with a thickness of 35 feet and dipping at 75° in a south-south-east direction. It can be followed along the ridge ·727 north of Reddipudur and Sevakavundanpalaiyam up to Makkalpudur. The average thickness of the band west of the Salem road is around 40 feet. The ore on the hill ·1500 is of fair quality.

(d) *Namagiripettai.*—Two miles south-east of Namagiripettai there are two bands, the western extremities of which are found half a mile south-east of Pachchudaiyanpalaiyam. From here they run in an east-north-east direction for nearly three miles. The southern band runs through hill ·1680 and continues eastwards into the valley where it is not visible. but reappear on hill·1330. The average thickness of this band is 30 feet but the magnetite content is rather low.

The northern band is seen on the northern flank of hill ·1680 and runs parallel to the southern one. Its thickness is also around 30 feet. The ore from these deposits appears to have been used in the indigenous smelting furnaces over a long period as indicated by the slag heaps present.

(e) *Narasimhapudur.*—This band, which is six miles long, is about half a mile south of Narasimhapudur. It can be, traced from near Tottikkadu and the eak ·4648 in the Kollimalai

in a west-south-west direction. The Namakkal-Rasipur road crosses it south of Narasimhapudur. It passes west-south-west through the hills ·1348 and ·839, up to Tirumalaipatti where it terminates. Just east of hill ·1348 it bifurcates into two branches for short distance. At the road section the band is represented by garnetiferous quartzite but in other places it is a magnetite-quartzite too poor in iron to be considered as ore. The thickness varies from 20 feet to 50 feet in different parts.

(*f*) *Kondamanayakkanur.*—Two parallel bands of magnetite quartzite are seen in an east-north-east—west-south-west direction for a distance of four and a half miles starting from the western flank of Nainarmalai and terminating near Murtinayakkanpatti. Where the bands cross the Salem-Namakkal road, they are obscured by soil but are seen in the hillock west of the road dipping at 50° to the south-south-east. In the hill ·915 further west, the northern band is 70 feet and the southern 25 feet thick. After this the northern one continues on plain ground for about a mile, up to Murtinayakkanpatti. The southern band is not seen to the west of the hill ·915. The average thickness of the northern band may be taken as 40 feet and that of the southern as 25 feet. The former appears to be richer in magnetite than the latter.

***Ore reserves*—**

			TONS.
Belukkurichchi.	$\frac{6 \times 5,280 \times 40 \times 100}{10}$	=	**12,672,000**
Namagiripettai.	$\frac{2 \times 3 \times 5,280 \times 30 \times 100}{10}$	=	**9,504,000**
Kondamanayakkanur (northern).	$\frac{4 \times 5,280 \times 40 \times 100}{10}$	=	**8,448,000**
Kondamanayakkanur (southern).	$\frac{5}{2} \times \frac{5,280 \times 25 \times 100}{10}$	=	**3,300,000**
	Total	..	**33,924,000**

7. *Kollimalai.*

This prominent hill mass is 20 miles long (north-south) and 12 miles broad (east-west). It rises to over 3,000 feet above the plains, some peaks being a little over 4,500 feet in altitude. The top of the hill is fairly flat. The general strike direction of the rocks is north-east—south-west.

Two bands of magnetite-quartzite are present. The one passing near Tottikkadu, to the north-east of the peak ·4648, is a little over half a mile long and 25 feet thick with a fair content of magnetite.

The second band is east of Valavandinadu and two miles east-north-east of the Mission settlement. It passes through the hamlet of Podambil and is two miles long (north-east—south-west) and 20 feet thick.

Area between Namakkal and Talamalai (see Plate VII).—The rocks of this area show a broad curvature in their strike, the concavity of the curve facing north. The strike is north-west—south-east in the west, east-west in the centre and north-east—south-west in the east. The dip is towards the concave side. The chief rocks are garnetiferous, amphibole and felspathic gneisses and magnetite-quartzites.

The bands of magnetite-quartzite are conformable to the others and have curved outcrops. There are two important bands in the western part of the area between Kirambur and the Salem-Tiruchirappalli road, while at the base of the Talamalai three or four more bands are seen.

7-*A*. *Kirambar* (*K-i*).

Two bands are seen between half a mile east-south-east of Kirambur and the hill ·1630 north of Tolur Karadu. The northern band is seen about half a mile south-west of Tottiyapatti and continues south-eastwards with a thickness of 20—30 feet. The ore is siliceous and contains a proportion of hematite. After crossing the Vallipuram cart-track, the band becomes 100 yards wide probably because of folding. It can be seen continuing to about half way up the northern slope of ·1630 where it appears to die out. The ore is fairly rich in magnetite and the thickness of the band is around 30 feet.

The southern band can be seen at the foot of hill ·897 on the top of which it appears to unite with the other band and to continue eastwards to the ridge ·1630. Its average thickness is also 30 feet.

7-*B*. *Villiyappanpatti—Tattayyangar Petta* (*VT-a*).

Band VT-a.—This is an important band more or less continuous over a distance of 25 miles east to west, though there are several apparent breaks in it.

The western end is about six furlongs north of Villiyappanpatti on a small ridge in which magnetite-quartzite is seen with east-west trend and dipping northwards. This outcrop is about half a mile long and 20 feet thick. After a break, a short band is seen on the same strike north-east of Kaliyankadu. This is only 100 yards long and 25 feet thick. (To the north of this outcrop there is another parallel one which is 300 yards long and 20 feet thick). Further east the same band is picked up three furlongs east of Aniyapurampudur where it is exposed for some 650 yards with a thickness of 20 feet. Beyond this, it is not seen for one and a half miles to the east, but is again seen in the hills ·924 and ·797 up to the road a short distance south-west of Valaiyapatti, the thickness varying between 10 and 60 feet.

After a break of two miles near Valaiyappatti, we see the band starting again from the border of the tank at Vadugapatti and continuing eastwards for five miles. From the hillock ·670 eastwards, the thickness of the band is on an average over

40 feet. Then it disappears for about 2½ miles and can be picked up again south of Andipatti where it is 50 feet thick. Then it proceeds towards Tattayyangarpettai with gradually diminishing thickness. It crosses the Tattayyangarpettai-Namakkal road at mile 8–7, beyond which it can be seen for nearly two miles, disappearing finally a furlong east of the Tattayyangarpettai-Moruppatti road. The band will be seen to be fairly continuous east of Valaiyappatti (on the Tiruchirappalli-Namakkal road), its total length being 11 miles and the average width 30 feet.

Band VT-b.—This is to the north of the main band. It extends from the base of the hill ·1010 for 1½ miles in an east-north-east direction. It is not seen for a mile near Valasiramani. Further east it is again picked up and runs for four miles up to a point one mile east of Kalingappatti. This band is 40 feet thick between Kalingappatti and Valasiramani, but the average thickness throughout its length of 5½ miles will be a little less.

Band VT-c.—This is south of the main band and consists two branches C-1 and C-2. The northern branch (C-1) can be followed from the hill ·1010 for four miles in an east-north-east direction partly along the ridge of ·629. Its average thickness is 40 feet. The southern branch (C-2), is about one furlong south of C-1 and can be seen to the east of a point one mile east of hill ·1010. After running separately for about three miles, it unites with C-1 about half-a-mile north-west of Jadamangalam. The united band C runs on ridge ·732 in which it is 100 feet thick. To the east of this hill it runs on low ground and disappears near Orakkarai village. It reappears again for short distances near Tattayyangarpettai. The total length of the band C may be taken as eight miles and the average thickness as 50 feet.

Band VT-d.—At the northern foot of hill ·732 there is a band of magnetite-quartzite which is three furlongs long and 25 feet thick. It is rather poor in magnetite content.

Band VT-e.—This has a length of two furlongs and is situated between the main band and band B, north-west of Jadamangalam. It is ten feet thick, with a fair proportion of magnetite.

7-*C. Mahadevi Hill* (*Hill*-1329).

This is about three miles north-west of Tattayyangarpettai and at the south-eastern foot of the Kollimalai. The rocks are highly folded and consist of garnetiferous and amphibole gneisses in the main, amidst which are beds of magnetite-quartzite.

(*a*) A band three furlongs long is found at the south-western foot of the hill·1329. Its average thickness is 30 feet. The magnetite content is rather low but the outcrops are marked by magnetite debris of high iron content.

(*b*) This band runs practically around the synclinal hill ·1344, except on the east. Its total length is 3¼ miles and the average thickness 40 feet.

(*c*) This is probably a branch of B and is seen on the northern flank of hill ·1344, just above the other hand. Its length is about six furlongs and thickness 25 feet.

(*d*) At the base of hill ·1344 there are two short bands just south of Muttarajapuram. East of the bands is three furlongs long and 10 feet thick. They are poor in magnetite.

(*e*) This runs east-west across the eastern flank of hill ·1344. It is about a mile long and 25 feet thick. It is also poor in magnetite.

***Ore reserves*—**

		TONS.
Kirambur (northern)	$\frac{5/2 \times 5,280 \times 25 \times 100}{5 \times 10} =$	3,300,000
Kirambur (southern)	$\frac{2 \times 5,280 \times 30 \times 100}{10} =$	3,168,000
VT (main) eastern portion	$\frac{3 \times 5280 \times 40 \times 100}{10} =$	4,752,000
VT (main) eastern portion.	$\frac{11 \times 5280 \times 30 \times 100}{10} =$	17,424,000
VT–b	$11/2 \times \frac{5280 \times 30 \times 100}{10} =$	8,712,000
VT-c	$\frac{8 \times 5,280 \times 50 \times 100}{10} =$	21,120,000
(*a*) Mahadevi	$\frac{3 \times 660 \times 30 \times 100}{10} =$	594,000
(*b*) Do.	$7/2 \frac{5,280 \times 40 \times 100}{10} =$	7,392,000
(*c*) Do.	$\frac{6 \times 660 \times 25 \times 100}{10}$	990,000
	Total ..	67,452,000

8. *Pachchaimalai.*

Only a small area near the southern margin of this hill mass was examined. The rocks have an east-west strike and a northerly dip of around 40°.

Pachchaimalai (*Pch.*).—A band six miles long is seen north of Ladapuram, exposed on the southern flank of this hill in an east-west direction. It continues westwards across the Manalodai stream but it is much obscured by forest growth. Further west, it forms a ridge north of Talur hamlet. Here the band contains much hematite and is 50 feet thick. It can be seen westwards as far as Melur. The average thickness of the band is about 35 feet.

Kanavoy.—A band, 2½ miles long of magnetite-quartzite is seen from the western part of Kurumbalur hill to the base of hill ·1473 across the Kanavoy village. South of the hill ·1404 it is seen for about three furlongs, then disappearing for about a mile and a half. It appears for another mile and cuts across the hill south-west of peak ·1093. It can be traced to hill ·919 and for half a mile west of it. Part of this shows garnetiferous quartzite in close association with the magnetite-quartzite. On the whole, this band is poor in ore.

Elambalur.—In the hill near Elambalur there is a band of poor ore which is one furlong long and 10 feet thick.

***Ore reserves*—**

		TONS.
Pachchaimalai ..	$\frac{6 \times 5{,}280 \times 35 \times 100}{10}$	11,088,000

VI.—NATURE AND COMPOSITION OF THE ORES.

The bands of ferruginous quartzites found in the Salem-Tiruchirappalli region are associated with a series of schistose and gneissic rocks, the most prominent amongst which are chlorite and talcschists, and amphibole and garnet bearing gneisses. They form a conformable series, though metamorphosed and often severely folded. Much of the succession seems to be of sedimentary origin but it is probable that some igneous materials have also been involved, e.g., some of the amphibolites may have been basic intrusives originally. The metamorphism has been responsible for the conversion of the ferruginous sediments, deposited perhaps as mixtures of ferric hydroxide and silica, into magnetite-quartzites. In some places the magnetite-quartzite bands contain amphiboles of the grunerite group which may have been produced in part by the thermal effect of granitic intrusions which are often found amidst these rocks. A varying amount of hematite is generally present in most of the bands, though occasionally it may be absent, or may attain a fairly high proportion. Quantitatively, however, hematite is unimportant as the average ore contains less than ten per cent of the amount of magnetite present. It is not possible to state, without undertaking intensive laboratory study of the materials, whether the hematite is all original or derived partly by reversion from magnetite after the latter had been formed.

Structure and texture of ore.—Texturally there are three types of ore, banded, gneissic and fine-grained. The banded variety, as the name suggests consists of alternate bands of magnetite and quartz. The thickness of the bands and the proportion of magnetite to quartz in the different layers vary from place to place. The average thickness of the layers is around ⅛ to ¼ inch, but individual layers may be thinner than 1/20th inch or as thick as 1 inch. The banded variety frequently shows minute folds, crumplings and fractures recalling those found in the hematite-quartzites of Singhbhum and the Orissa States.

The gneissic variety is akin to the banded one but the magnetite generally tends to be segregated into fairly coarse lenticular or 'augen'-shaped grains. This arrangement makes the banding irregular.

The third type is granular or rather equigranular, being composed of a more or less uniform mixture of grains of magnetite and quartz. The uniformity may be broken here and there by small aggregated patches or by the presence of some larger grains. When the grain size is very fine, the rock appears to be aphanitic and the individual grains require the aid of a magnifying lens to distinguish.

Most of the ores in the deposits described here can be put under the banded variety, the gneissic and granular types being developed only locally.

Sampling.—The samples were taken, so as to be representative of the more important bands, by making cuts across the bands and reducing the samples in accordance with the usual practice. Ordinary black powder (gun powder) was used for loosening the rock in hard and massive exposures. Each sample, as collected at first, would have mounted to $\frac{1}{2}$ to $\frac{3}{4}$ ton. It was then broken down to 1 inch size, quartered and then reduced to 1/8 inch size.

Though a total of more than 150 samples were taken, only 30 could be analysed—two-thirds by Mr. J. N. Majumdar in the Indian School of Mines, Dhanbad, and the rest by Mr. D. Krishnan in the Geological Survey of India, Calcutta. Ten other samples were also partially analysed by the second author in the Geology Department, Presidency College, Madras. The results are shown in the accompanying table.

The range and the average of the analyses are given in the last two columns. For each constituent the average refers only to those samples in which it was determined and not for the total number. The analyses confirm the fact that the iron content of the ordinary ores is of the order of 35—40 per cent and the silica content about 50 per cent. There is little or no sulphur and the phosphorus is variable and in some cases high. There is some indication that the phosphorus can be decreased during concentration, but more work should be done on large samples in order to settle this point, as it is one of importance.

In the analyses done in the Geological Survey of India, the titania was reported as in traces or absent; but other samples from the same deposits were reported to contain 0·5 per cent or more of this constituent in the analyses done at the Indian School of Mines, Dhanbad. As titania is reported to be present in a few of the older analyses, it may be assumed that there is generally a small amount (of the order of 0·5 to 1 per cent) present in most of the ores.

Some alumina, lime and magnesia are generally present, but these are likely to be in appreciable quantities in ores

containing much amphibole. As the amphibole is generally found as thin streaks in the ore, it may not be possible to pick it out during the working. But any method of concentration is likely to eliminate this mineral largely.

VII.—SUMMARY OF RESERVES OF ORE.

The details of the different deposits have been given in previous pages together with the reserves calculated in each. These figures are brought together here.

	TONS.	TONS.
Kanjamalai—		
A	31,680,000	
B	9,504,000	
C	9,504,000	
Ap	3,960,000	54,648,000
Godumalai—		
G (*a*)	7,260,000	
(*b*)	900,000	
(*c*)	2,640,000	
(*d*)	1,650,000	12,450,000
Perumamalai—		
(*a*)	4,224,000	
(*d*)	2,3 6,000	
(*e*)	1,584,000	
(*f*)	660,000	
(*g*)	792,000	
Puduppalaiyam	792,000	10,428,000
Attur area—		
Attur S. W. of Thammampatti ..	1,980,000	
(*c*)	792,000	
(*d*) Part	1,056,000	
(*e*)	840,000	
Singiliyan kombai		
(*a*)	60,000	
(*b*)	5,230,000	
(*c*)	1,3 0,000	
(*d*)	396,000	11,724,000
Chitteri Hills—		
Belur F (*a*)	3,960,000	
(*b*)	14,256,000	
(*c*)	14,256,000	
(*d*)	2,640,000	
(*e*)	5,544,000	
Sittilingi (*f*)	1,848,000	
(Sit) (*g*)	240,000	
(*h*)	12,672,000	55,416,000
Thirthamalai		
Ta	15,840,000	
Ta (northern)	7,392,000	
Tb	10,560,000	
Tb (northern)	7,392,000	
Tc	2,640,000	
Td	1,320,000	
Modukuli	2,376,000	47,520,000

Between Rasipur and Namakkal—			**TONS.**
Belukkurichchi	.. ..	12,672,000	
Namagiripettai	.. ..	9,504,000	
Kondamanayakanur (N)	..	8,448,000	
Do. (S)	..	3,300,000	
			83,924,000
Kollaimalai—			
Kirambur (N)	.. ..	3,300,000	
Do. (S)	.. ..	3,168,000	
Villiyappanpatti–Tattayyangarpettai—			
VT-a (main, western)	..	4,752,000	
VT-a (main, eastern)	..	17,424,000	
VT-b	.. .. ..	8,712,000	
VT-c	.. .. ..	21,120,000	
Mahadevi (a)	.. ..	594,000	
Do. (b)	.. ..	7,392,000	
Do. (c)	.. ..	990,000	
			67,452,000
Pachchaimalai	.. ..	11,088,000	11,088,000
	Total of all the deposits ..		304,650,000

For all the deposits (except one) a depth of 100 feet from the outcrop has been assumed. Some of them form hills several hundred feet high above the level of the adjacent plains and must contain ore to a much greater depth. As the deposits are all of bedded character, they can be assumed to be regular and more or less of uniform thickness. Hence, in actual working, they can be expected to yield very much more than the above calculation show, probably anything up to three or four times this quantity.

If systematic mapping of the Salem-Tiruchirappalli-Arcot region is taken up, a number of other deposits of iron ore are likely to be found. These, together with the poorer deposits (containing, say, less than 25 per cent magnetite in the rock) will contain a large tonnage, the exploitation of which will be purely a question of the cost of crushing and concentration.

VII.I—CONCENTRATION OF THE ORE.

As no facilities were available at Madras for applying dry tabling or wet concentration methods, only magnetic concentration was tried. Even for this only an inefficient inverted type of electro-magnet (poles standing up) was available during a short period. Hence an ordinary laboratory horse-shoe magnet was used for most of the separations though a few were tried with the electro-magnet for which current of 0·7 ampere was sufficient to attract the magnetite and separate it from the other minerals.

The samples were crushed to pass 0·33 mm. mesh. About 20 gms. were taken for the tests and the sample as well as

the concentrate weighed. The weight of the concentrate is given as a percentage of the sample used.

Sample number.	Concentrate weight per cent.	Sample number.	Concentrate weight per cent.
A–13	51.8	Ta 1	26.0
A–16 .. .	44.4	Tb–2	65.0
A–22	49.2	Tb–3	36.0
A–27	47.3	Tb–5	52.1
Ab-2	31.4	Tb–6	43.4
Ab-6	48.6	Tb–7	55.0
B-4	47.6	Tc–1	52.3
B-10	47.8	Tc–2	50.2
C-8	56.9	Tc–3	53.9
G-10	43.5	Td–1	58.5
G-4	38.6	VT.1	39.2
Sit-1	8.0 *	VT–2	38.0
Sit-2	49.4	VT–3	48.0
Bl–2	51.5	VT–4	32.0
Bl-3	12.2 *	VT–5	44.3
		VT–6	31.6
		Pch	43.0
		Ki	51.0

To test the efficiency of concentration (by ordinary horse-shoe magnet) a few of the concentrates were analysed for their iron content (by Mr. A. P. Subramanyam, M.SC., Geological Assistant).

Concentrate number.	Fe_2O_3 per cent.	Fe per cent.
Tb 5	81-2	56-8
C-8	92-0	64-4
B-10	81-5	57-1
VT-5	88-9	62-2
A-13	80-6	56-4
G-10	81-2	56-8

It is clear that, in general, the ores are amenable to concentration easily by magnetic methods to give over 55 per cent iron. A higher grade concentrate can be obtained either by passing the concentrate through the magnet a second time or, in the case of the fine-grained ores by finer crushing. The fineness to which the ore will have to be crushed in large scale operations will vary from deposit to deposit in accordance with the coarseness of the texture. This can easily be ascertained by measurements on the different types of ores.

The hematite in the ores will remain with the tailings in magnetic concentration. It may not be worth recovering if the proportion is small. But, roasting of the high-hematite ore under reducing conditions will convert the hematite into magnetite and make it amenable to magnetic concentration.

As the chief minerals in the ore are quartz, magnetite, hematite and amphibole, the ordinary methods of dry and wet concentration should prove successful in separating the magnetite and hematite from the associated lower density minerals. Without actually trying out the different methods in large scale experiments it is not possible to assess their relative efficiency or cost.

IX.—UTILI ZATION OF THE DEPOSITS.

Lack of Fuel.—A great difficulty confronting many industries in South India, and especially metallurgical industries, is the lack of coal. Though there are coal deposits in the Hyderabad State, none of the coals is known to be suitable for making hard (metallurgical) coke. Coke or coal has, therefore, to be imported from Bengal or Bihar by sea or rail and the cost at points in the interior of the Madras Presidency comes to about Rs. 15 to Rs. 18 per ton in normal times. Not only is the high price a handicap to the consuming industries but at a time of crisis the transport system may be unable to cope with the demand and to make adequate and timely deliveries. Hence some method by which this dependence on coal coming from a long distance is at least partially eliminated will be preferable.

Alternative ways of smelting the ores by which this dependence on coal can be cut down to a minimum have, therefore, to be examined. These are—

(1) Smelting in blast furnace using charcoal fuel.

(2) Smelting in the electric furnace (using a small quantity of charcoal for reduction only and not for generation of heat).

(3) Other processes—*e.g.*, the Stuerzelberg process.

Mining of the Ores.

Practically all the important ore bodies occur at some height above the round level. Open-cast quarrying can be adopted at least in the thicker ore bodies. The general steepness of the beds will make the adoption of metal mining methods necessary with suitable modifications according to the position, size and structure of the ore bodies. Iron ore being a cheap commodity, the cost of mining, haulage and handling must be kept as low as possible. Where the deposits are at a height and contain large quantities it may be feasible to instal wire ropes for haulage of the ore to the plains.

Concentration.

The ores are magnetite-quartz-schists containing varying proportions of magnetite and quartz. They frequently also contain small quantities of hematite and an amphibole, the latter apparently formed as a result of the metamorphism of the ores. In the great majority of the ore bodies the amphibole will be a minor constituent. The hematite is often closely associated with the magnetite. The ore varies considerably in grain size. The coarse material is gneissic, the magnetite appearing as 'augen'. Some varieties are very fine grained. All the

ore will have to be crushed and concentrated in order to eliminate the impurities such as quartz and amphibole. The information available so far shows that most of the ores will have to be crushed to pass 10 mesh (per linear inch) for effecting a good separation. In some cases the ore may have to be crushed much finer. As the fineness to which crushing must be done will depend on the texture of the ore, it can be judged only after gaining some experience in determining the optimum grain size of different types for the purpose of concentration.

As by far the larger part of the ore is magnette, electro-magnetic separation should be the most satisfactory method of concentration. The small proportion of hematite associated with the magnetite will be drawn up with the latter. If the proportion of hematite is appreciable, it would be useful to employ also tabling or wet washing. The best combination of methods will have to be worked out for the different types of ores. There seems to be little doubt that the ordinary average ore, containing 35–42 per cent iron, can be improved in grade to one with about 60 per cent iron. The ore can then be briquetted or sintered, if necessary, before smelting.

SMELTING.

Coke blast furnace.—The non-availability of coal in South India will make the manufacture of iron in the ordinary coke blast furnace an expensive process. The use of coke will enable operations to be conducted in units larger than those possible with charcoal fuel or electrical energy. But as every ton of iron produced will require nearly one ton of coke for smelting, the cost of the raw materials will become high and will prevent the manufactured products from competing effectively with similar products made at more favourable localities.

Charcoal blast furnace.—It is possible to use charcoal instead of coke for smelting. The charcoal consumption per ton of pig iron produced is about 16 or 17 cwt. Smelting with charcoal will be feasible as in Mysore, if a regular supply can be assured by reserving an adequate area of forests for providing the wood for conversion into charcoal. One ton of charcoal can be got from 4 to 5 tons of wood. If a production of, say, 100 tons of pig iron per day is contemplated, it may be necessary to make 100 tons of charcoal. This would involve the provision of $365 \times 100 \times 5 = 182{,}500$ tons of wood per year which, on the basis of a yield of 1/3 to $\frac{1}{2}$ ton of timber per year per acre, would require an area of between 365,000 and 547,500 acres of forest land. For steel making, of course, more charcoal will be needed, and a larger area of forest will have to be reserved.

Electric smelting.—Electric energy can replace fuel for smelting, only a small quantity of carbon as charcoal (or coke) being needed to reduce the iron oxide to metal. The charcoal needed for reduction will be around 6 to 7 cwt. per ton of iron produced, *i.e.*, about a third of what would be required for both heating and reduction.

According to Pring (' The Electric Furnace ', Longmans Green and Company) the production of one ton of pig iron would require one-third h.p.—year (say 2220 kwh.) the electrode and charcoal consumption being 12 lb. and 8 cwt., respectively.

Bradly Stoughton (' Metallurgy or Iron and Steel ', McGraw Hill, 1934, p. 204) gives details about the " Electrometall " furnace at Domnarfvet in Sweden. A furnace with a capacity of 60 tons per day as a load of 6,300 K.W. which gives an output of 3·5 tons of pig iron per Kw-year. The current consumption amounts to 2,300–2,400 kwh. per ton of pig iron. If very high grade ore is used, the production of iron can be increased to 70 tons per day with a saving of 150 kwh. per ton of iron. The carbon electrode consumption is 10 Kilograms per ton of iron.

Regarding the relative costs of electric energy and charcoal fuel, Dr. J. W. Mellor has stated (' Comprehensive Treatise on Theoretical and Inorganic Chemistry ', Volume XII, p. 599) that the cost of electric energy for iron smelting should not exceed £4 per Kw-year. This would be equivalent to about Rs. 54 per Kw2 year or 0·1 anna per Kwh. Pring (' The Electric Furnace '. p. 163) has stated that, to be on a competitive basis, the cost of 1 Kw-year of power should be equal, if not cheaper, than that of 3 tons of coke.

For economy in operation and for maintaining a well trained and adequate technical staff, it may be necessary to plan production on the basis of 100 tons of iron per day. If electrical energy is available at the rate of 0·1 anna or less per unit (Kwh.), there is every chance of the electric furnace produce being able to stand competition with the coke blast furnace product in South Indian markets.

It is necessary to emphasize here that the smelting operations must not stop with the making of only pig iron for sale. To be really profitable, the operation should include the conversion of pig iron into steel (ordinary or alloy steels) and steel products.

Dr. Dubey and Mr. Karunakaran have given an approximate estimate of the cost of manufacture of steel at Salem in the electric furnaces shown below:—

	RS.	A.	P.
Iron ore 1·6 tons at Rs. 3 per ton	5	2	0
Limestone (150 lb.) at Rs. 2 per ton	0	2	0
Charcoal 800 lb. at Rs. 14 per ton	5	0	0
Electrodes 20 lb. at Rs. 400 per ton	4	0	0
Electric energy 3,500 units at 1 pie per unit.	18	0	0
Refractories, repairs, etc.	5	0	0
Depreciation	2	0	0
	39	2	0
Overhead, supervision, labour, etc.	25	0	0
Total per ton of steel ...	64	2	0

*The Stuerzelburg Process**.—The plant for the Stuerzelberg process consists of a mill for producing and delivering pulverised coal or charcoal into the furnace, a pre-heater, and a rotary furnace. Preliminary roasting is done if necessary. The mixture of ore, coal and lime (flux) is pre-heated by the waste gases and the pre-heated material passes into the rotary furnace where it is heated by the fuel (coal dust), the highest temperature developed being around 1,500°C. A pasty slag and sponge-iron are then formed, the slag surrounding the masses of sponge-iron. The slag composition is kept highly basic for effective desulphurisation. The waste gases pass through a slag and ash catcher and thence through the regenerator to the pre-heater.

This and the Krupp-Renn process,† which have been developed since 1934 are suitable for low grade ores like lateritoid materials, residue from roasting of pyrite, etc., which cannot easily be beneficiated. The Salem ores are, however, easily concentrated. It would therefore appear that, provided electric energy can be made available at cheap rates, electric smelting would be the most suitable for the treatment of the Salem ores. The price which electro-metallurgical industries can afford to pay for electricity is around 1/12 to 1/10 anna per Kwh. or say, around Rs. 50 per Kw-year.

Fluxes and refractories.—The auxilary materials required for the iron and steel industries are fluxes and refractories. Both limestone and dolomite are available in the Salem district itself as also in Tiruchirappalli and Coimbatore. Amongst the refractories fire clay, magnetite, chromite and siliceous materials like quartzites and quartz schists are available within the Madras Presidency, and mostly within short distances of the iron ore deposits. These materials will be available to an iron and steel works in the Salem district as no higher cost than what other similar works are paying for them.

As a preliminary to the working and smelting of these ores it will be necessary to conduct investigations on a fairly large scale on crushing, methods of concentration, sinterling or briquetting and smelting, in order to determine the best practice to be followed and to work out the approximate cost of the operations. These must be carried out by specialists either in well equipped laboratories or in works where there are facilities. With sustained effort, it should not be difficult to solve the problem of smelting these ores and making them serve as the basis of an iron and steel industry in the Madras Presidency.

**Demag News* (English) April 1938—C 7—C 11.
Hofmeist-d H, *min Journ* (London) CCVI' Aug 12, 1938, P. 757.
†Min Journ (London) CCVI, July, 8, 1938, P. 648

ANALYSES ON IRON-ORES.

(Salem-Trichinopoly Region.)

	* A-8.	† A-13.	† A-17.	† A-26.	* A-29	* B-1.	* B-4.	* B-6.	† B-10.	* C-3.	† C-8.	* C-12.	† F-1.	* G-1
SiO_2 ..	44·44	44·60	50·34	46·55	49·07	45·90	36·20	46·64	42·85	47·76	45·40	48·28	52·20	52·52
Fe_2O_3 ..	42·15	38·20	31·19	37·60	37·11	34·19	36·30	34·37	39·91	35·76	37·41	33·89	36·21	32·58
FeO ..	9·46	12·45	12·86	12·08	11·22	14·89	12·37	15·42	11·79	13·49	11·01	13·66	6·36	11·39
P ..	0·136	0·086	0·118	0·10	0·086	0·144	0·086	0·161	0·113	0·136	0.086	0·131	0·118	0·118
S ..	0·002	..	..	..	0·066	Nil	..	0·001	..	Tr.	..	Tr.	Nil	Nil
TiO_2 ..	Tr.	0·85	0·50	0·53	Nil	Nil	0·65	Nil	0·65	Nil	0·75	Nil	0·55	Nil
Al_2O_3 ..	..	1·17	1·28	0·43	..	..	0·84	..	1·62	..	2·41	..	1·43	..
CaO ..	..	1·32	1·22	1·05	..	..	1·55	..	1·45	..	1·35	..	1·00	..
MgO ..	..	1·64	1·59	1·86	..	..	2·19	..	1·61	..	2·08	..	2·30	..
MnO ..	Nil	..	..	..	Nil	Tr.	..	Nil	..	Nil	..	Nil	..	Nil
H_2O ..	0·65	..	..	..	0·43	0·21	..	0·17	..	0·43	..	0·30	..	0·46
Fe ..	37·86	36·42	31·80	35·68	34·70	35·51	35·01	36·05	37·07	35·53	34·71	34·35	30·26	31·69

	† G-4.	* G-8.	† G-10.	* G-13.	† H-1.	‡ Ki-1.	‡ Ki-3.	† Ki-4.	† Tch-1.	† Sit-1.	† Sit-2.	‡ Ta-1.	‡ Th-1.	‡ Tb-3
SiO_2 ..	50·02	46·51	42·82	56·24	48·35	48·56	48·80	44·05	42·29	44·58	42·43	47·53	49·60	49.80
Fe_2O_3 ..	37·41	37·61	46·94	34·42	36·58	..	..	40·51	43·[illegible]9	47·93	41·38	..	..	..
FeO ..	9·58	11·57	6·36	7·19	9·66	..	..	10·00	10·36	2·79	10·64	..	..	..
P ..	0·061	0·193	0·118	0·070	0·060	0·054	0·042	0·091	0·086	0·056	0·136	0·039	0·053	0·054
S ..	..	Nil	..	Nil	..	Nil	Nil	..	..	..	..	..	Nil	Nil
TiO_2 ..	0·58	Nil	0·70	Nil	1·45	..	..	0·53	Nil	0·63	1·10	Tr.	Nil	Tr.
Al_2O_3 ..	0·21	..	1·49	..	2·75	..	..	0·83	1·82	2·66	1·66	..	..	..
CaO ..	0·85	..	0·50	..	0·25	..	..	0·78	0·87	0·75	1·25	..	..	..
MgO ..	1·73	..	0·54	..	1·40	..	..	2·65	1·68	0·75	0·35	..	..	..
MnO ..	..	Nil	..	Tr.	..	..	..	..	..	..	..	..	..	..
H_2O ..	..	0·27	..	0·48	..	..	..	..	..	..	..	..	..	..
Fe ..	53·61	35·33	37·80	29·69	33·06	37·26	35·40	36·10	38·47	35·71	37·21	36·20	36·40	[illegible]

	†Tb-4.	†Tb-5.	‡Tb-6.	‡Tc-1.	†Tc-2.	‡Tc-3.	‡Bl-1.	‡Bl-2.	†Bl-5.	†VT-5.	†VT-6.	Range.		Mean.
SiO_2 ..	47·55	47·43	49·20	48·1	46·74	45·76	50·40	47·58	50·48	45·09	41·25	41·2	56·2	47·28
Fe_2O_3 ..	41·66	38·21	..	..	34·63	..	..	..	36·81	41·99	50·80	31·2	50·8	38·52
FeO ..	7·39	10·64	..	..	15·66	..	..	..	7·79	9·58	4·12	4·1	15·7	10·06
P ..	0·026	0·017	0·093	0·163	0·030	0·053	0·044	0·040	0·086	0·070	0·096	0·017	0·193	0·088
S ..	..	..	0·26	Nil	..	Nil	0·018	Nil	..	..	..	Low	..	0·007
TiO_2 ..	Nil	0·63	Tr.	..	0·88	..	..	..	0·88	0·45	0·60	Nil	2·75	0·40
Al_2O_3 ..	2·42	1·81	..	..	1·03	..	..	..	2·35	1·86	1·58	0·21	2·7	1·58
CaO ..	0·15	0·20	..	..	0·10	..	..	..	0·47	0·58	0·37	0·10	1·55	0·80
MgO ..	0·11	0·11	..	..	0·26	..	..	..	1·37	0·74	0·84	0·11	2·65	1·34
MnO ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
H_2O ..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·38
Fe ..	34·88	35·00	37·00	31·45	36·39	32·79	39·6	36·92	31·79	36·81	38·73	29·7	39·6	35·27

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† Analyst—J. N. Majumdar (Indian School of Mines, Dhanbad).

‡ Analyst—N. K. N. Ayyangar (Presidency College Laboratory, Madras).

A, B, C = Kanjamalai; F = Belur; G = Godumalai; H = Hill near Valanpadi; Ki = Kirambur; Pch = Pachchaimalai; Sit = Sittilingi; Ta, b, c = Thirthamalai; Bl = Belukkurichchi; **VT** = Villiyappanpatti-Tattayyangarpettai.

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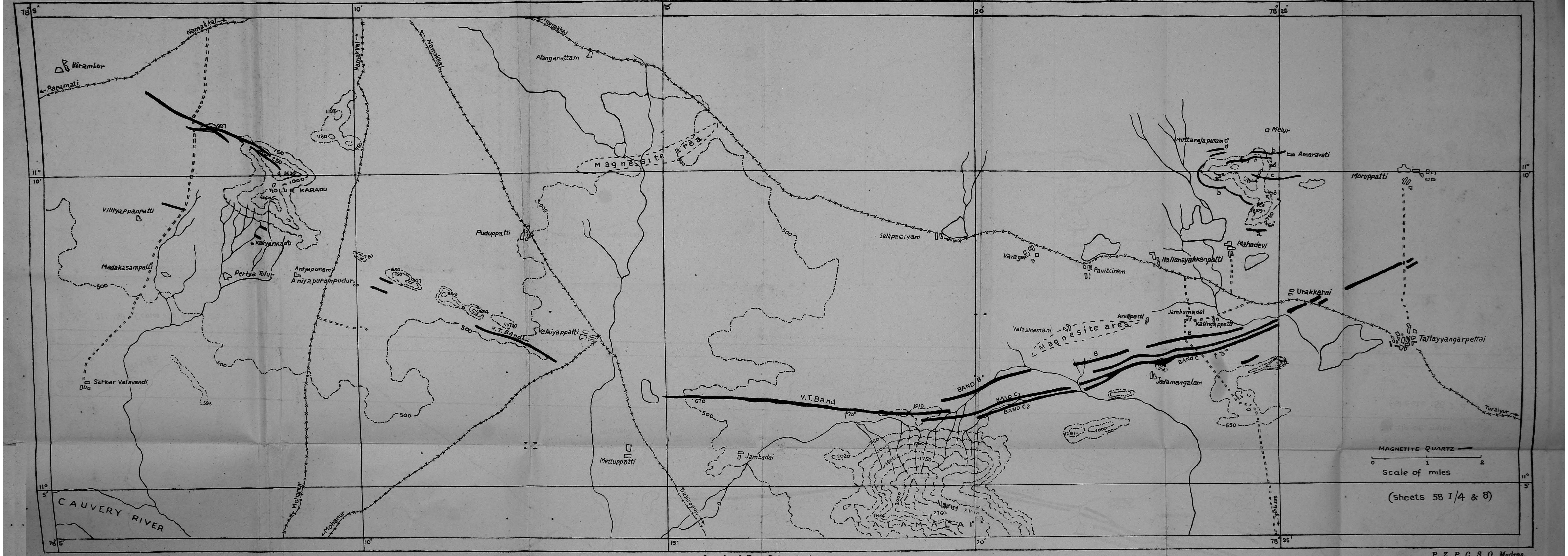

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APPENDIX II.

(*See* paragraph 41, Chapter V.)

Preliminary report on benefication of Low Grade Magnetite from Salem of the Dirctor, National Metallurgical Laboratory, Jamshedpur, forwarded by the Council of Scientific and Industrial Research in November 1957.

Five samples of magnetite (marked HB, LB-A, LB-B and LB-C) each weighing 4 tons, from the (i) higher, (ii) middle and (iii) lower belts respectively of the Kanjamalai hills at Salem, Madras, were received for beneficiation and sintering tests in the Ore-dressing division of the laboratory. The identification marks on the various bags had disappeared by the time they reached Jamshedpur. Consequently, all the five samples had to be mixed for investigation purposes. One or two bags of four of the samples, viz., LB-A, LB-B, LB-C and MB, could, however, be identified and they were kept aside for determining the mineralogical compositions. The sample as received consisted of lumps varying from ½ inch to 4 inches in size. A representative sample of the mixed ore was prepared and a portion crushed to –10 mesh for experimental work. Wet screen analysis of the –10 mesh sample and examination of the various fractions showed that quartz was the principal gangue and magnetite was fairly liberated at about –48 mesh size. The sample as received assayed Fe, 36·5; SiO_2 44·2; Al_2O_3 1·92; CaO 1·8; MGO 0·9; P 0·09 and TIO_2 0·2 per cent.

Dry magnetic separation at a low intensity of the sample at –35 mesh produced a concentrate assaying 60·3 per cent Fe and 14·3 per cent SIO_2 with a recovery of 71·9 per cent. Magnetic separation at —48 mesh improved the grade to 61·7 per cent Fe for the same recovery. A preliminary wet magnetic separation of the –48 mesh sample yielded a concentrate assaying 61·0 per cent Fe and 13·3 per cent SIO_2 with a recovery of 90· per cent Fe.

Further tests are in progress to improve the grade of concentrate by reducing the silica content.

Sintering tests will be taken up after determining the best method of concentrating the ore.

A PRELIMINARY REPORT ON THE REDUCIBILITY OF SALEM MAGNETITE ORE.

The reducibility test should be regarded as an essential guide in assessing the suitability of any iron ore for its utilisation in blast furnace or in other iron-making units, either directly or after various agglomerating processes such as sintering, nodulizing, pelletizing, briquetting, etc. The test itself is a complex one because of the many factors that have to be considered in the study of the reducibility of the iron ore such as (i) the inherent reducibility of the ore, (ii) porosity, (iii) size of the ore, (iv) size and shape of the furnace, (v) temperature, (vi) pressure, (vii) velocity of the reducing gas and (viii) gangue materials,

etc. The reducibility tests as such are by no means the absolute index of the behaviour of the ores in the reduction furnaces but serve as a fair guide in assessing the different ores. The results when compared with certain standard ores that had been utilised successfully in the production of iron under well established processes, however, give a fair idea about the reducibility of the ores.

The relative reducibility test makes it possible to eliminate many factors that are common and with this principle, the effect of size of the particles, temperature and gas velocity alone were considered in the study of the reducibility of Salem magnetite ore. Tests were conducted under similar conditions on uncrushed lumps of Salem magnetite ore and crushed but unconcentrated samples of the ore with hydrogen as reducing agent. Further tests are being carried out at different stages of concentration of the ore.

The Salem magnetite ore contained 36·5 per cent Fe and 44·20 per cent SIO_2 the same weight were prepared by cutting and grinding the lumps of Salem magnetite ore and these were reduced at various temperatures and gas velocities. Tables I and II indicate the results of the tests carried out on the uncrushed ore.

TABLE I.

Effect of rate of flow of hydrogen on the reduction of iron ore.

H_2 Gas Velocity—900 cc. per minute.

Total time of reduction—70 minutes.

	Temperature °C.	Per cent Reduction:
1	700	50·41
2	800	68·6
3	900	47·7

TABLE II.

Effect of rate of flow of hydrogen on the reduction of iron ore.

Temperature—900°C.

Total time of reduction—70 minutes.

	Rate of flow.	Per cent reduction.
1	800 cc. per minute	35·4
2	900 cc. per minute	47·7
3	1000 cc. per minute	53·08

It is observed that the reducibility of the ore increased with increase in temperature up to 800°C, while further increase of temperature reduces the reducibility. An increase in gas velocity promotes the reduction rate at 900°C. Figs. I and 2 show the effect of temperature and hydrogen gas velocity respectively on the reduction rate on the uncrushed ore.

It is also observed that even though both the temperature and gas velocity increased the rate of reduction slightly, the overall per cent reduction never exceed 70 per cent after 120 minutes. It has been found that uncrushed samples do not give very reproducible results as the different lumps may vary in composition.

The next series of experiments were carried out on the crushed and unconcentrated sample in order to get a homogeneous sample. The crushed magnetite ore were made into briquettes with dextrine as a binding agent and samples were prepared from these briquettes. The reducibility tests were conducted with these samples at different temperatures and gas velocities. The test was conducted first on –10 mesh size sample because the entire Salem magnetite ore was crushed to –10 mesh and further concentration were being carried out from these crushed sample. Table III indicates the results obtained on different mesh size and uncrushed ore.

TABLE III.

Effect of mesh size on the rate of reduction.

Rate of flow of hydrogen = 1,000 cc. per minute.

Temperature of reduction = 900°C.

Total time of reduction = 70 minutes.

Mesh size.	Per cent reduction.
1 Lump ore	53·08
2 – 10 mesh.	62·0
3 – 32 + 72	77·6
4 – 100	55·1

Fig. 3 shows the effect of particle size on the rate of reduction of the ore at 900°C and hydrogen gas velocity of 1,000 cc. per minute. It is observed that the reducibility has a maximum value for –32 + 72 mesh sample and that –100 mesh sample has a poor reducibility.

Table IV indicates the effect of temperature on the reducibility of – 32 + 72 mesh samples.

TABLE IV.

Effect of temperature on the rate of reduction.

Mesh size— – 32 + 72.

Rate of flow of hydrogen—1,000 cc. per minute.

Total time of reduction—70 minutes.

	Temperature °C	Per cent reduction.
1	600	48·5
2	800	59·8
3	900	77·6
4	1000	69·5

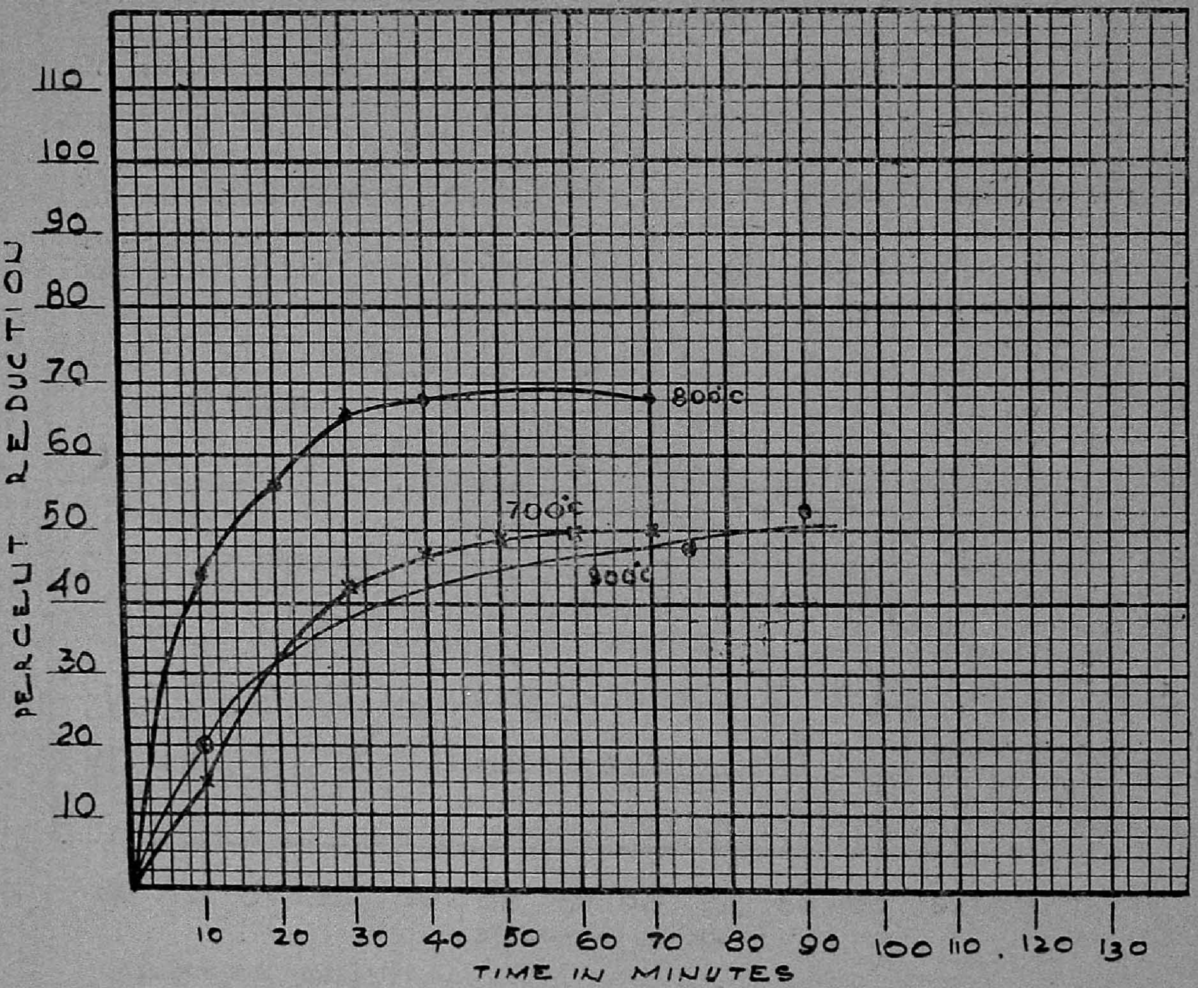
The rate of reduction is shown in Fig. 4 and it is observed that a maximum reduction 77·6 per cent is obtained at 900°C and the total reduction decreased at 1000°C.

It is clearly seen from Figs. 1, 2, 3 and 4 that the optimum mesh size, temperature and gas velocity and all of them have the effect of increasing the rate of reduction in the initial period of 20 minutes of reduction only and thereafter no appreciable difference is observed. This may be due to the high silica content of the ore which might combine with iron to form fayalite and making the further reduction a very slow process. Further experiments are being carried out to confirm these findings.

With these preliminary data on unconcentrated samples, the test results at different stages of concentration will be compared and the improvement in the reducibility of this ore will be observed.

A preliminary experiment conducted at 800°C and 1,000 cc. per minute hydrogen gas velocity with the concentrated ore of – 32 mesh size analysing 65 per cent Fe and 8·5 per cent SIO_2 showed a percentage reduction of 71·99 per cent for 70 minutes and 84.14 per cent after 120 minutes respectively.

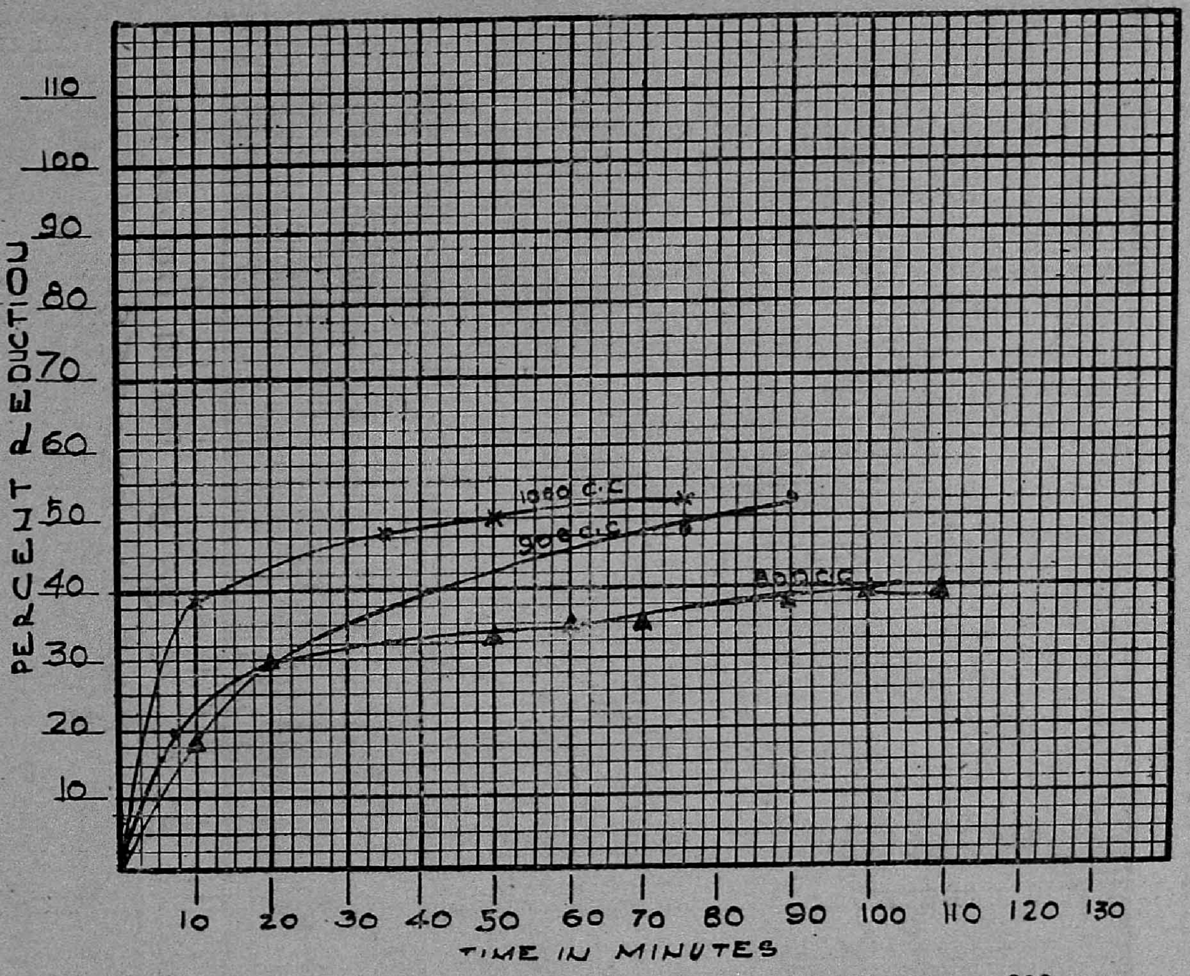
EFFECT OF TEMPERATURE ON THE RATE OF REDUCTION.



[Lump ore H_2 = 900 c. c. Per Minute.

Fig. 1.

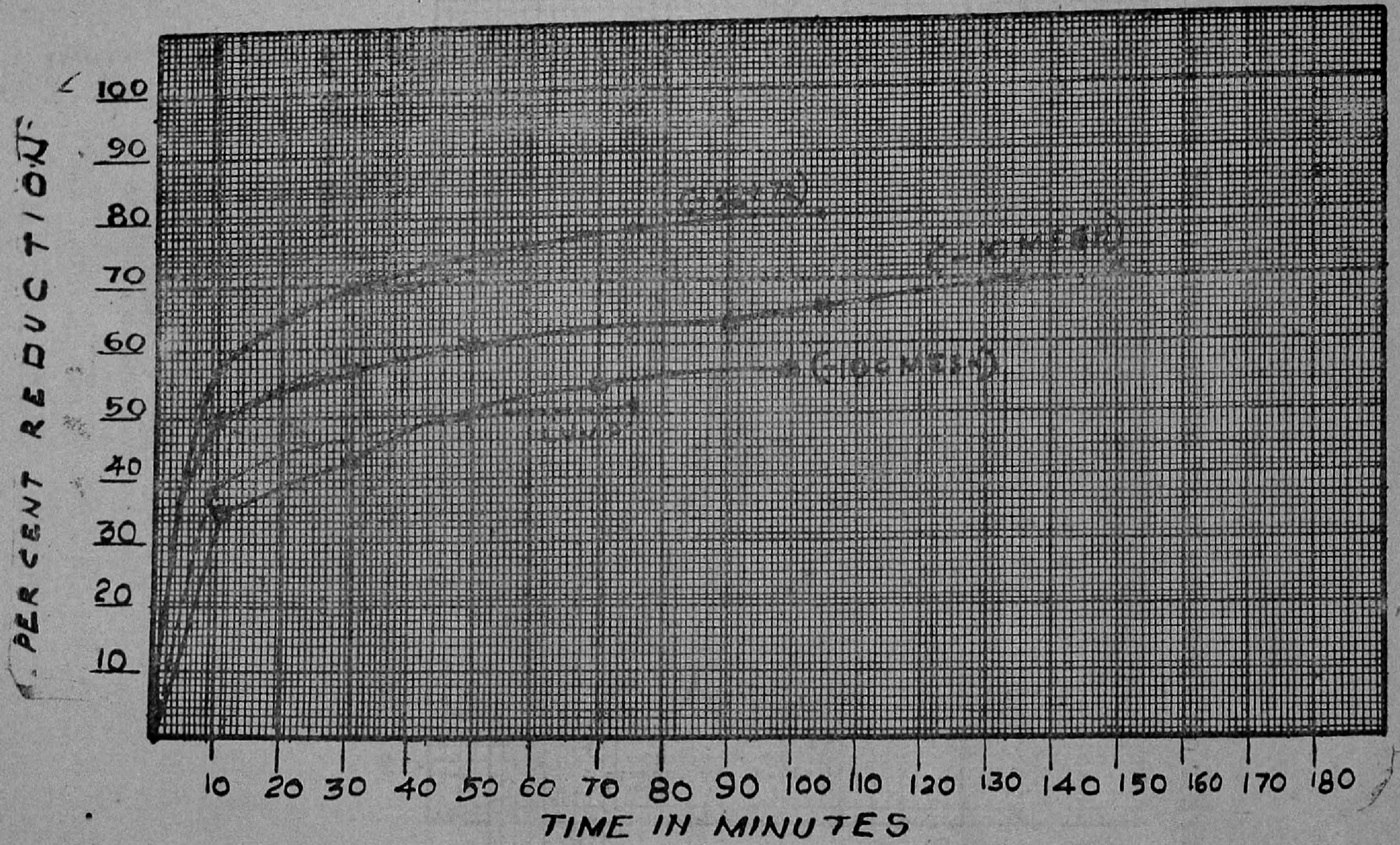
EFFECT OF HYDROGEN FLOW ON THE RATE OF REDUCTION.



Lump ore 900 c.c.

FIG. 2.

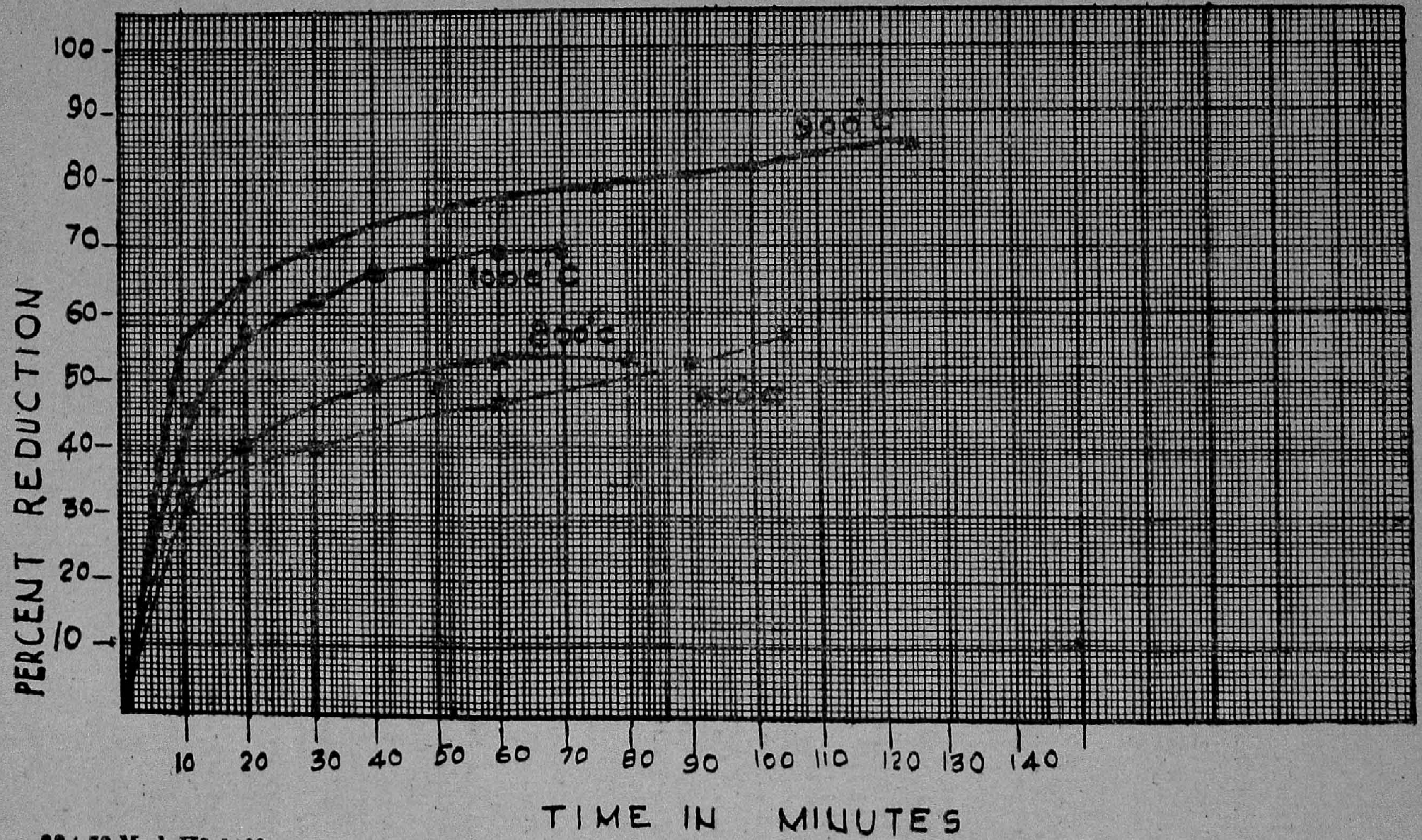
EFFECT OF MESH SIZE ON THE RATE OF REDUCTION.



900 c H_2 1000 c.c. Per Minute

FIG. 3.

EFFECT OF TEMPERATURE ON THE RATE OF REDUCTION



— 32+72 Mesh H2 1000 c.c. per minute.

Fig. 4.

APPENDIX III.

(*See* pragraph 41, Chapter V.)

Investigation Report No. IR 116/58, dated January 1958. on "Benefication of Low Grade Magnetite from Salem Madras" Part I by Sarva Shree S. K. Banerjee and P. I. A. Narayanan, Ore Dressing Division, National Metallurgical Laboratory, Jamshedpur

ABSTRACT.

[The results of studies on beneficiation of a magnetite ore assaying 36·5 per cent Fe and 44·2· SiO_2 and containing principally magnetite, quartz, hematite, goethite, kyanite and sillimanite are presented. Dry magnetic separation of the sample did not produce satisfactory results. Wet magnetic separation -48 and -65 mesh sizes yielded magnetic concentrates assaying 62·5 per cent Fe, 11·1 per cent SiO_2 and 64·3 per cent Fe, 9·6 per cent SiO_2 with a recovery of about 88 per cent iron in both cases. Dry magnetic separation at -10 mesh followed by wet magnetic separation of the rougher concentrate at -48 mesh produced a final concentrate assaying 6[illegible]·98 per cent Fe and 12·1 per cent SiO_2 with a recovery of 86·5 per cent Fe. Tabling the sample at -48 mesh gave a concentrate assaying 65·21 per cent Fe and 8·8 per cent SiO_2 with an overall recovery of 82·8 Fe, but higher recovery could be obtained at the expense of grade of the concentrate. Tabling at -48 mesh and magnetic separation at -65 mesh can, therefore, yield nearly the same results, because the slime and tailing loss during tabling almost balanced the loss of hematite in the non-magnetite product.

Results obtained by pilot plant trials employing tabling as well as magnetic separation are also presented.]

INTRODUCTION.

In connection with a co-ordinated and comprehensive scheme of research on Salem Magnetite, viz., (i) beneficiation of the ore, (2) study of the sintering characteristics of the concentrate and (3) study of the reducibility of the ore as received, as well as of the beneficiated material and (4) the possibilities of production of iron in Pilot plant low shaft furnace, a sample of magnetite was received in the National Metallurgical Laboratory from the Government of Madras. Various aspects of the scheme are being investigated in stages, the present report covers investigation results obtained on the amenability of the ore to beneficiation by normal ore dressing methods.

SAMPLE.

Five samples of magnetite from Salem, Madras, marked LB-A, LB-B, LB-C, MB and HM each weighing 4 tons were despatched by the Assistant Director of Industries and Commerce, Madras. The identification marks on the bags had been obliterated during transit. Consequently all the five samples have to be mixed for investigation purposes. One or two bags from each of four of the samples could, however, be identified and were used for mineralogical analysis. As received, the sample consisted mostly of lumps from " to 4" in size. A representative sample

weighing about 5 tons from the mixed ore was prepared and crushed to – 10 mesh for investigation. Judged by the resistance offered to crushing, the ore should be considered as hard.

The sample as received assayed—

	PER CENT.
Fe	36·5
FeO	5·04
SiO_2	44·2
Al_2O_3	1·92
CaO	1·8
MgO	0·9
TiO_2	0·2
P	0·09
Loss on ignition	0·2

A wet screen analysis of the – 10 mesh samples is given in Table 1.

TABLE 1.

Screen analysis.

Size (mesh)	Weight per cent.
– 10 + 14	17·5
– 14 + 20	22·1
– 20 + 28	16·6
– 28 + 35	10·7
– 35 + 48	8·1
– 48 + 65	5·2
– 65 + 100	5·0
– 100 + 150	3·6
– 150 + 200	2·3
– 200	8·9
	100·0

Ore microscopic studies of the ore conducted by Mr. M. S. Chopra, Petrologist, showed that nearly 20 per cent of the iron minerals present in the ore was in the form of hematite, 5 per cent in the form of goethite and the rest as magnetite. The chief gangue mineral was quartz with small amounts of kyanite, sillimanite and mica. Over 90 per cent of the magnetite was liberated at – 48 mesh. The petrological report on the ore samples by Mr. M. S. Chopra is given in the appendix at the end of this report.

TESTS.

The problem in beneficiating the ore was confined to rejection of quartz which is the principal gangue by magnetic and gravity methods.

Dry Magnetic Separation at – 35 mesh.—The – 10 mesh sample was crushed to – 35 mesh and passed through a laboratory electromagnetic separator at a low intensity. The results are given in Table 2.

TABLE 2.

Dry magnetic separation at — 35 mesh.

Products.	Weight per cent.	Assay per cent Fe.	Assay per cent SiO_2	Distribution per cent Fe.
Magnetic 1 ..	43·5	60·34	14·34	71·9
Magnetic 2 ..	12·6	44·3	33·4	15·3
Non-Magnetic ..	43·9	10·59	..	12·8
Feed ..	100·0	36·5	..	100·0

NOTE.—The sieves mentioned in this report are from Tyler's standard.

The magnetic fractions contained interlocked particles of magnetite, and free silica and hence the next test was performed with a – 48 mesh feed.

Dry magnetic separation at – 48 *mesh.*—The results obtained by dry magnetic separation at – 48 mesh are given in Table 3.

TABLE 3.

Dry magnetic seperation at –48 mesh.

Products.	Weight per cent.	Assay per cent. Fe.	Assay per cent. SiO_2	Distribution per cent Fe.
Magnetic 1	42·7	61·7	12·92	72·0
Magnetic 2	12·5	46·35	31·35	15·8
Non-Magnetic	44·8	10·0	..	12·2
Feed ..	100 0	36·6	..	100 0

The results did not appreciably improve by employing a finer feed. Even at – 48 mesh the grade of concentrate and recovery were not quite satisfactory. The magnetic fractions were found to be contaminated with free silica mechanically carried over, indicating that wet magnetic separation might yield better results.

Wet magnetic separation at – 48 *mesh and* – 65 *mesh samples.*—The sample was crushed to – 48 and – 65 mesh respectively and subjected to wet magnetic separation. The results are given in Table 4.

TABLE 4.

Wet magnetic seperation of –48 and –65 samples.

Size (mesh)	Products.	Weight per cent.	Assay per cent. Fe.		Assay per cent. SiO$_2$		Distribution per cent. Fe.	
-48	Magnetic 1	43·5	63·8	62·5	9·5	11·1	76·1	88·9
	Magnetic 2	8 4	55·7		19·66		12 8	
	Non-Magnetic	48·1	8·4		..		11·1	
	Feed ..	100·0	36·5		..		100·0	
-65	Magnetic 1	42·8	65·54	64·3	8·2	9·0	76·7	88·6
	Magnetic 2	7 6	57·4		11·9		11·9	
	Non-Magnetic	49·6	8·45		..		11·4	
	Feed ..	100·0	36·6		..		100·0	

NOTE.—The sieves mentioned in this report are from Tyler's standard sieve series.

No responsibility is taken for the results except in so far as they apply to the sample tested.

As expected, better results were obtained by wet magnetic separation of the sample compared to dry magnetic separation and the grade of concentrate at – 65 mesh was better than that with a coarser grind for the same recovery of iron.

To determine the effect of iron minerals contributing to the loss of iron in the non-magnetic tailing, a sink and float test was conducted using a liquid of sp. gr. 2·9. Examinations of the sink under an ore microscope showed that the iron minerals were predominently hematite (85 per cent) followed by goethite. Small amounts of magnetite and bornite were also present.

Two stage magnetic separation of the – 10 mesh sample.—An attempt was made in this test to eliminate a large bulk of the gangue at a coarse size, followed by magnetic separation at a finer size to obtain a high grade of concentrate.

The – 10 mesh sample was passed through the Laboratory electromagnetic separator at a low intensity. The magnetic fraction was subsequently ground to – 48 mesh and subjected to wet magnetic separation. The results are given in Table 5.

TABLE 5.

Dry magnetic separation of −10 mesh sample and Wet at −48 mesh.

Products.	Weight per cent.	Assay per cent. Fe.	SiO₂	Distribution per cent. Fe.
Magnetic 1 ..	49·1	63·0	10·82	83·5
Magnetic 2 ..	2·6	43·3	36·66	3·0
Non-Magnetic (Wet) −48 mesh ..	23·7	13·18	..	8·5
Non-Magnetic (dry) −10 mesh ..	24·6	7·6	..	5·0
Feed ..	100 0	37·0	..	100·0

The two magnetic concentrates when mixed assayed 61.98 per cent Fe and 12.1 per cent SiO_2 with an overall recovery of 86.5 per cent Fe. The grade of concentrate as well as the recovery were slightly lower than those obtained by straight wet magnetic separation at −48 mesh. This method, however could reject 25 per cent by weight of gangue at −10 mesh and thus save some grinding cost, requiring to grinding only 75 per cent by weight to −48 mesh.

Tabling of −48 mesh feed.—The −10 mesh sample was ground to −48 mesh and sized into two fractions in a hydraulic classifier. The slime was collected as overflow. The sand portions were separately treated on a Denver Shaking Table with the following results given to Table 6:—

TBLE 6.

Tabling of −48 mesh sample.

Products.	Weight per cent.	Assay per cent. Fe.	SiO2	Distribution per cent. Fe.
Coarse Fraction—				
Table concentrate	31·4	66·68	6·98	57·4
Table Tailing	14·7	7·55	..	3·0
Fine Fraction—				
Table concentrate I	10·4	68·0	5·33	19·4
Table concentrate II	4·5	48·74	29·53	6·0
Table Tailing ..	23·0	8·16	..	5·2
Slime	16·0	20·56	..	9·0
	100·0	36·5	..	100·0

A concentrate of grade 67·0 per cent Fe and 6·5 per cent SiO_2 could be obtained for a recovery of 76.8 per cent, but if a higher

recovery was aimed at by mixing concentrate II also, the grade would drop to 65.2 per cent Fe and 8.8 per cent SiO_2. Tabling had yielded a higher grade of concentrate than that obtained by magnetic separation, though recovery was lower. For the same feed size, (viz. –48 mesh) and same grade of concentrate (say 62.5 per cent Fe) tabling and magnetic separation can yield as iron recovery of about 87 per cent. The results obtained by tabling at –65 mesh, were not quite so good, due to higher slime loss.

Humphrey's Spiral Test.—The –10 mesh sample was ground to –48 mesh and passed over a Humphrey's Spiral. The results are given in Table 7.

TABLE 7.

Treatment of —48 mesh sample on Humphrey's Spiral.

Products	Weight per cent.	Assay per cent. Fe.	Assay per cent. SiO_2.	Distribution per cent. Fe.
Spiral concentrate	43·5	62·0	12·5	73·3
Spiral Middling ..	10·6	32·28	50·87	9·3
Spiral Tailing ..	45·9	13·94	..	17·4
	100·0	36·8	..	100·0

The results were not as those obtained by tabling or wet magnetic separation.

PILOT PLANT TESTS.

Having determined the optimum conditions for obtaining the best results by magnetic separation and tabling pilot plant tests were conducted with the ore ground to the fineness indicated in the sieve analysis below:—

Straight Tabling.—About 1·5 tons of the –10 mesh sample was ground in a continuous red mill (16″ × 32″) and the mill discharge fed to a pair of Denver Shaking Tables working in parallel. Grinding was carried in open circuit under the following conditions:—

Total rod charge ..	**495 lb.**
Average pulp density of—	
Mill discharge ..	**About 55 per cent solids**
Feed rate	**374 lb./hour.**

A screen analysis of the rod mill discharge is given in Table 8 and the results of the test in Table 9.

TABLE 8.

Sieve Analysis of Rod-Mill Discharge.

Size (Mesh)	Weight per cent.
+48	5·6
−48+65	13·0
−65+100	18·3
−100	63·1
	100·0

TABLE 9.

Straight Tabling.

Products.	Weight 3.	Assay per cent. Fe.	Assay per cent. SiO_2	Distribution per cent. Fe.
Table concentrate	42·1	67·0	5·56	77·6
Table tailing ..	57·9	14·1	..	22·4
Feed	100·0	36·4	..	100·0

The results checked up well with those obtained by batch tests. Higher recovery could be obtained, for a correspondingly lower grade of concentrate.

Wet Magnetic Separation.—About 1·5 tons − 10 mesh ore was ground to the size indicated below, which is slightly finer than the feed, prepared earlier for tabling:—

TABLE 9.

Sieve analysis.

Size (mesh)	Weight per cent.
+ 48	3·5
− 48 + 65	9·0
−65 + 100	19·5
— 100	68·0
	100·0

The ground product was passed through a Wet Magnetic Separator at Ghatsila belonging to the Department of Atomic Energy of the Government of India. A Magnetic concentrate and a non-magnetic tailing were collected. The results are given in Table 10.

TABLE 10.

Wet Magnetic Separation.

Products.	Weight per cent.	Assay per cent. Fe	SiO_2	Al_2O_3	CaO	MgO	P	Distribution per cent. Fe
Magnetic ..	48·4	62·1	13·3	1·12	1·0	0·7	0·081	81·2
Non-magnetic.	51·6	13·5	..	..	..	..	..	18·8
Feed ..	100·0	37·0	..	..	..	..	..	100·0

The grade of concentrate as well as recovery were lower than those obtained earlier in batch tests, because the magnetic intensity and other factors could not be properly adjusted to the requisite optimum, at Ghatsila for this work. Another cause could be that the feed was somewhat coarser, containing 12·5 per cent by weight in the +65 fraction, as compared to a −65 mesh feed employed for the batch tests. By employing a finer feed and carrying out magnetic separation under optimum conditions, results comparable to those of the batch tests are to be expected in practice. The principal object in doing out this large-scale magnetic separation test at Ghatsila was to collect sufficient magnetite concentrate for subsequent sintering tests on the concentrate.

SUMMARY AND CONCLUSION.

Five samples of Salem Magnetite were received from the Assistant Director of Industries and Commerce, Government of Madras, for beneficiation and other tests. The combined sample assayed 36.5 per cent Fe, 44.2 per cent SiO_2. 1.92 per cent Al_2O_3, 1.8 per cent CaO, 0.9 per cent MgO, 0.2 per cent TiO_2 and 0·09 per cent P. The iron minerals in the sample were magnetite, hematite and goethite. The principal gangue mineral was quartz with small amounts of kyanite and sillimanite. Over 90 per cent of the magnetite was liberated at −48 mesh size.

Dry magnetic separation of the sample at −48 mesh did not give encouraging results.

Wet magnetic separation of the sample at −48 mesh produced a concentrate assaying 62·5 per cent Fe and 11·1 per cent SiO_2 with a recovery of 88·9 per cent Fe whereas by employing a −65 mesh feed, the grade of concentrate improved to 64·3 per cent Fe and 9·6 per cent SiO_2 for almost the same recovery. The liberated hematite was lost in the non-magnetic tailing.

Dry magnetic separation at −10 mesh followed by cleaning of the magnetic fraction by wet magnetic separation after grinding to −48 mesh gave a final concentrate assaying 61·98 per cent Fe and 12·1 per cent SiO_2 with a recovery of 86·5 per cent Fe. The result should be considered as satisfactory in relation to those obtained by straight wet magnetic separation at −48 mesh. The two-stage process saves unnecessary grinding of

about 25 per cent by weight of gangue which could be rejected at -10 mesh and requiring only the remaining 75 per cent to be ground to -48 mesh for final cleaning.

Tabling the sample at -48 mesh after classification yielded a combined concentrate assaying 67·0 per cent Fe and 6·5 per cent SiO_2 with a recovery of 76·8 per cent Fe. The recovery improved to 92·8 per cent Fe by mixing a concentrate II, when the grade dropped to 65·2 per cent Fe and 8·8 per cent SiO Tabling yielded a better grade of concentrate than that obtained by magnetic separation, though the recovery was a somewhat lower. For a concentrate of grade about 62·5 per cent Fe at -48 mesh size, tabling and magnetic separation could be expected to give the same recovery of about 87 per cent iron. Hematite which got lost by magnetic separation could be recovered by tabling, in spite of slime loss during the latter method. The results obtained by tabling a -65 mesh feed were not encouraging due to high slime loss.

PILOT PLANT TESTS.

Pilot Plant Tests were carried out with the ore employing tabling as well as wet magnetic separation.

Tabling the sample yielded a concentrate assaying 67·0 per cent Fe and 5·56 per cent SiO with an iron recovery of 77·6 per cent. The results compared very well with those obtained in the batch tests. Higher recovery can be obtained by collecting a correspondingly lower grade of concentrate.

A single pass of the ore through the wet magnetic separator belonging to the Department of Atomic Energy, Government of India, yielded a magnetic product assaying 62·1 per cent Fe and 13·2 per cent SiO with a recovery of 81·2 per cent iron in the product. The grade and recovery were lower than those obtained in small-scale laboratory tests, because the magnetic intensities and other factors could not be adjusted to optimum limits at Ghatsila. The feed also was somewhat coarser containing 12·5 per cent by weight in the $+65$ mesh fraction, as compared to a -65 mesh feed employed for the batch tests. Better results should be obtained in practice by employing a finer feed and carrying out the magnetic separation under optimum conditions. The presence of appreciable amounts of hematite and goethite was responsible for the loss of iron in the non-magnetic fraction.

ACKNOWLEDGMENT.

The thanks of the authors are due to Dr. B. R. Nijhawan, Director, for his interest, to Mr. S. B. Mondal for chemical analysis, to Mr. M. S. Chopra for Petrological studies, to Messrs. G. P. Mathur and S. B. Dasgupta for their assistance during pilot plant tests, and to the Department of Atomic Energy and Indian Copper Corporation for permission to use their Wet Magnetic Separator and providing facilities for this work.

ANNEXURE & APPENDIX III.

PETROLOGICAL REPORT ON SALEM MAGNETITE ORE BY M. S. CHOPRA.

Character of samples marked LB-A, LB-B, LB-C and MB as studied from hand-picker specimens.

Sample LB-A.—There are essentially two varieties in this sample, viz., (*a*) coarse crystalline compact variety, (*b*) coarse crystalline banded variety, the former predominating over the latter. Both are quite fresh and tough.

The minerals associated with magnetite in these varieties are quartz, hematite, limonite, red and yellow ochres, kyanite and sillimanite, amphiboles and traces of bornite. Quartz occurs in the form of veins and irregularly distributed crystals. In the banded type, the quartz veins alternate with magnetite veins. Hematite occurs in the veins penetrating the magnetite veins. Kyanite and sillimanite occur as rounded xenoliths in magnetite crystals and veins. The sample is characterized by high magnetite and hematite percentage in coarser grains.

Sample LB-B.—The sample is characterized by the two varieties :—

(*a*) Fine grained compact variety.

(*b*) Coarse grained banded variety.

The latter resembled the coarse grained banded variety of sample LB-A. Mineral association is same as in LB-A. Amount of magnetite is almost the same, while that of kyanite and sillimanite increases. The fine grained variety has greater amount of kyanite and sillimanite in the form of xenoliths, higher per cent of amphiboles and lesser amounts of free silica. Primary hematite also appears to be less.

In the coarse grained banded variety, the amount of quartz increased, while that of kyanite, sillimanite, etc., decreased. The amount of hematite, limonite and ochres also increased.

Sample LB-C.—This sample almost always exhibits banding, though the extent of banding may vary. Leaching of the surface of some samples indicates proximity to surface. The leaching out of the ochre has produced small cavities. This type is comparatively softer and whenever a fresh surface is exposed there is evidence of higher amounts of hydrated iron oxides and ochres.

The amount of kyanite and sillimanite, etc., appears to be lesser than in LB-A, LB-B. While that of quartz seems to be higher The amount of limonite and ochres also increases.

Sample MB.—The sample is the softest and predominantly schistose in nature. Sometimes banding of quartz and magnetite is observed with the former predominating. In the schistose variety magnetite has penetrated along the plans of schistosity in the quartz—sillimanite and kyanite schists. Magnetite percentage in this variety is small. As the magnetite percentage increases the schistosity gives way to banding. The content of sillica in the form of quartz increased at the expense of sillimanite and kyanite. The grain size also increased. In some cases, content of amphiboles and epidote is higher than that of kyanite and sillimanite. Here the quartz content is less while that of magnetite quite appreciable. Limonite and ochres are quite high.

Summarising the above observations, it can be said that though the sample LB-A, LB-B and LB-C resemble each other to a great degree, they differ from MV considerably.

Content of magnetite in the LB-A, LB-B and LB-C is almost same while the grain size gradually decreases in that order, the softness increases, limonite and the ochres increase while primary hematite increases. The percentage of kyanite appears to be greatest in LB-B with LB-A and LB-C having lesser in that order.

Sample MB differs from the others in that it contained lesser quantity of magnetite, the percentage of sillimanite, kyanite, quartz, amphiboles, etc., increased. Its schistosity and weathered nature makes it comparatively softer.

Sample HB.—Not a single bag bearing the identification mark HB could be picked up.

Petrological examination of the mixed sample.—The petrological examination of LB-A, LB-B, LB-C, MB and HB samples crushed together in equal proportion revealed the following minerals under transmitted light.

	PER CENT.
Opaque minerals (iron oxides mostly)	48
Quartz	43
Kyanite and sillimanite	5
Moscovite and biotite, etc.	2
Rest (amphiboles, epidote, garnet, etc.)	2
Total ...	100

Systematic examination of different mesh fractions revealed that nearly.

5 to 10 per cent of gangue is in free state in −10+14 mesh fraction 60 to 65.

60 to 65 per cent of gangue is in free state in—20+28 mesh fraction 60 to 65.

70 to 75 per cent of gangue is in free state in —28+35 mesh fraction 60 to 65.

80 to 85 per cent of gangue is in free state in —35+48 mesh fraction 60 to 65.

90 to 92 per cent of gangue is in free state in —48+65 mesh fraction 60 to 65.

95 to 96 per cent of gangue is in free state in —65+100 mesh fraction 60 to 65.

97 to 98 per cent of gangue is in free state in —100+150 mesh fraction 60 to 65.

Ore microscopic studies of different fractions shows that nearly 20 per cent of the iron ore is in the form of hematite and nearly 5 per cent in the form of goethite (as a major constituent of limonite). Both primary and secondary hematite was observed. In the former case it occurred either as veins penetrating into the magnetite crystals (Fig. 1) or followed the octahedral cleavage planes, giving widmanstetten like texture.

In the other case martitisation (alteration to hematite) (Fig. 1) starts along the margins and cracks in the magnetite gradually advancing inwards. Finer grained magnetite is generally more completely altered than the coarser variety. The hematite veins vary in thickness between 0·0042 mm and 2 mm. About 75 per cent of hematite is, however, liberated at —48 mesh size.

FIG. 1.—PHOTOMICROGRAPH SHOWING PRIMARY HEMALITE VEINS (WHITE) PENETRATING INTO MAGNETITE (LIGHT GREY). BOTTOM RIGHT HAND CORNER SHOWS EARLY STAGES OF MARTITISATION OF MAGNETITE. DARK GREY MINERAL IS QUARTZ (ETCHED WITH $SnCl_2$ + HCL) POLARISED LIGHT × 140 SQUARE REPRESENTS 200 MESH APERTURE.

APPENDIX IV.

(*See* paragraph 41, Chapter V.)

Investigation Report No. IR. 121/58, dated February 1958 on "Reducibility of Salem Magnetite ore" By Sarvabhara. M. Subramaniam and P. P. Bhatnagar of National Metallurgical Laboratory, Jamshedpur.

ABSTRACT.

An attempt is made to assess the reducibility of Salem magnetite iron ore based on hydrogen reduction of lumps and briquettes made thereof. The temperature of reduction varied from 700°—1,000° C with different rates of hydrogen flow. Reduction rate was observed to considerably slow down after 70 per cent of reduction was completed. Reduction experiments were also conducted after table concentration of the magnetite ore, these concentrates containing 5–6 per cent silica. Likewise, tests were also undertaken on concentrate containing 13 per cent SiO_2 obtained after wet magnetic separation of the raw ore. These studies showed that reducibility of the ore concentrates compared favourable with that of high grade hematite iron ores used in India at present for iron production.

INTRODUCTION.

Reducibility test determines the suitability of an iron ore as such for iron production in a blast furnace or in other iron-making units or after agglomerating processes, such as, sintering, nodulising, pelletizing, briquetting, etc. Factors affecting such reducibility studies of an iron ore are (i) inherent reducibility, (ii) porosity, (iii) size, (iv) size and shape of the furnace, (v) temperature, pressure and velocity of reducing gas, (vi) gangue materials, etc. Different investigators have essentially used the same equipment for reducibility studies but there is a marked difference in testing procedures and methods of presenting results. Many indices have been proposed for representing their test results. Joseph expressed the "reducibility" as the time required for 90 per cent reduction and found that the reciprocal of the time required for 90 per cent reduction varied directly with porosity. Lewis [2] reported that reducibility was a function of lump size and indicated that the time required for 90 per cent reduction was directly proportional to the volume of ore cube. Udy and Lorig[3] came to the conclusion that diffusion of the reducing gas through pores of the ore was the rate controlling factors in reduction. Working both with hydrogen and carbon monoxide as reducing agents, Tenenbaum and Joseph [4] reported that hydrogen gave reducibilities about four times as high as carbon monoxide. Saunders and wild[5] studied the effect of ore size and found reduction can be influenced by diffusion of heat as well as by chemical or gaseous diffusion. Gust Bitsianes and Joseph[6] identified the different phases in a partially reduced iron ore and proclaimed that gaseous reduction of dense iron ore was a topochemical process in which reduction took place at distinct interfaces between

solid phases or layers. Tenenbaum and Joseph [7] worked out the effect of pressure on rates of reduction and found that the reducibility increased with increase in pressure. Edstrom [8] studied the mechanism of reduction of pure, natural hematite and magnetite crystals by hydrogen and carbon monoxide and concluded that the faster reduction of Fe_2O_3 was due to an earlier and more extensive formation of pores in reduction products.

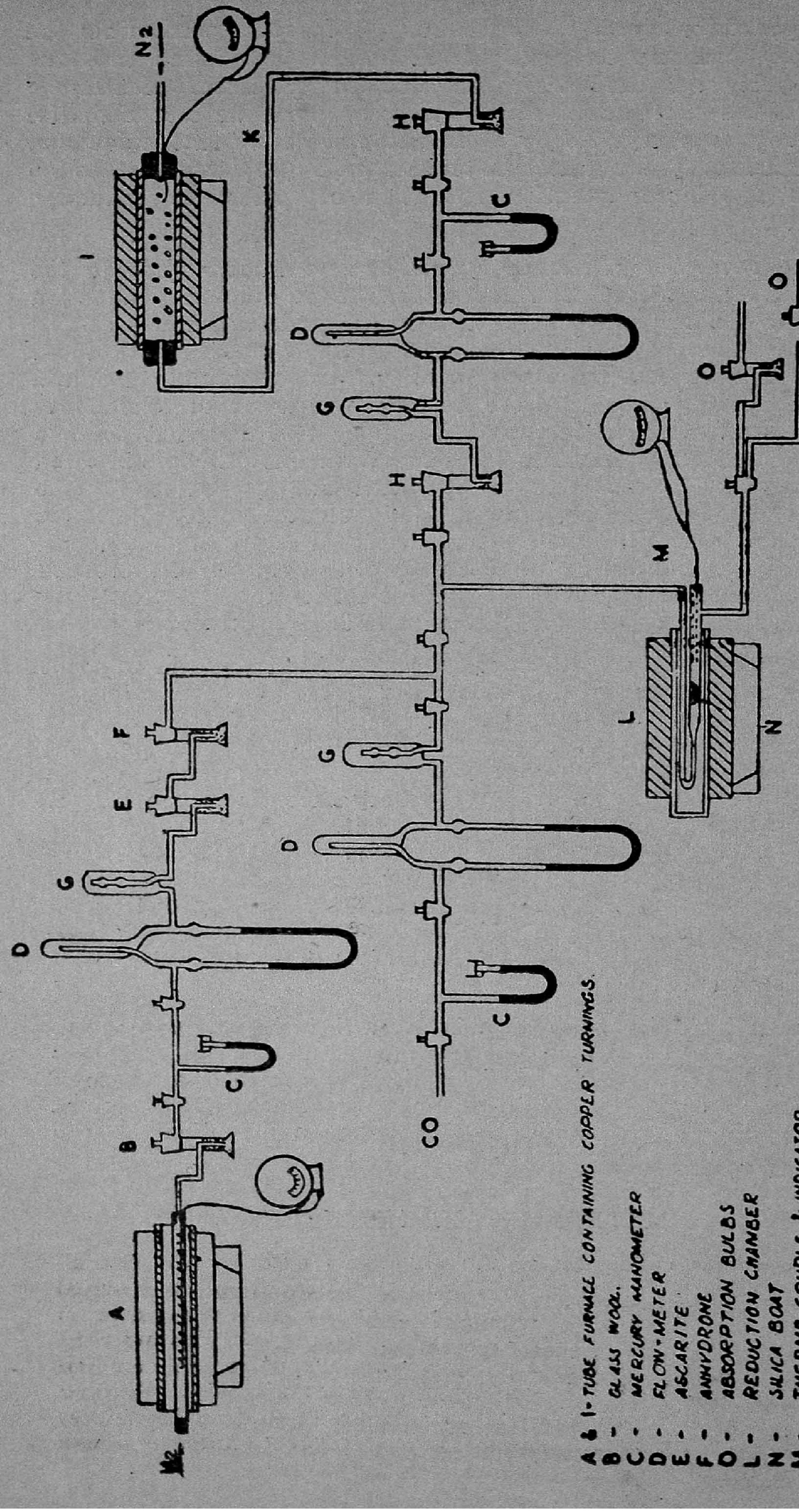
The reducibility test as such, by no means provide the absolute index of the behaviour of the ores in industrial reduction furnaces but serve in general as a useful guide in relative assessment of different ores. These results are compared with those obtained with standard iron ores used successfully for iron production and these provide a relative criterion of reducibility of the ores. Such a relative reducibility test makes it possible to eliminate many common factors. With this principle in mind effect of size of particles, temperature and gas velocity alone were considered in the present study of reducibility of Salem magnetite iron ore. Tests were conducted under similar conditions on (1) lumps of Salem magnetite ore, (2) on crushed samples of the ore and (3) on the ore-concentrate after different stages of its concentration through ore-dressing methods.

The total reserves of iron ore in Salem district and in adjacent Tiruchirappalli district in South India are of the order of 600 million tons. The ore is mainly a mixture of magnetite and quartz in equal proportions containing about 35 to 40 per cent iron, medium-to-low phosphorous and very low sulphur. A typical analysis of the Salem magnetite ore is given below: FeO 5·04 per cent, Fe 36·5 per cent, SiO_2 44·20 per cent, Al_2O_3 1·92 per cent, CaO 1·8 per cent, MgO 0·90 per cent. P 0·093 per cent, loss of ignition 0·2 per cent. On account of the high silica, the ore is not suitable for direct reduction in the blast furnace as it will not only form compounds that are difficult to reduce but the slag volume will be too voluminous to be profitably handled.

The reducibility tests have been carried out on ore concentrates obtained by tabling and wet magnetic separation. It was essential to briquette the crushed ore as was done in the case of concentrate obtained on wet magnetic separation. The report includes the results obtained by hydrogen reduction of the briquettes.

MATERIALS AND METHODS.

A schematic diagram of the apparatus used for the reducibility studies is indicated in Figure A. Reduction was carried out in a bent silica combustion tube contained in a tube furnace. The bent tube enabled pre-heating of hydrogen. The weighed cubical sample placed in a silica boat, was put in the combustion tube and heated in an atmosphere of nitrogen. Purified oxygen-free nitrogen flushed the system preventing either oxidation or reduction before the reduction temperature was



REDUCIBILITY TEST APPARATUS
FIG. A

reached. A chromel-alumel thermo-couple was placed over the centre of the sample. The temperature was controlled by means of a Simmerstat. Purified commercial cylinder hydrogen was used for reduction.

Hydrogen was purified of oxygen by passing over heated copper turnings and alkaline pyrogallate solution. The moisture was removed by absorption towers containing magnesium perchlorate. The flow of the hydrogen gas was measured by means of a calibrated flow-meter.

In each test, desired rate of gas flow was adjusted and test was started. The product of reduction, i.e., H_2O was absorbed in alternate absorption bulbs inserted at exit end of reduction furnace. Every 10 minutes, one absorption bulb was removed and weighed alternatively. At the close of the experiment, whole system was flushed with nitrogen and after cooling, the silica boat with the sample was removed and weighed. The tests were conducted at temperature of 700°, 800°, 900°, 950° and 1,000°C and at various gas velocities of 600 c.c. to 1,000 c.c. per minute.

Calculations.—The increase in weight of the absorption bulb at any instant indicated the weight of water formed and all the oxygen in the water was supposed to be, have been liberated by the reduction of Fe_3O_4 The reduction percentage was calculated as the per cent of oxygen removed during the reduction period from the oxygen available as Fe_3O_4 in the ore or concentrate. The following example illustrates the method of calculation:—

Example.

Weight of water formed = X gms.

Weight of oxygen in the water formed $= X \times \frac{16}{18} = \cdot 89\,X$ **gms.**

Weight of ore taken = A gms.

Percentage of iron in the ore = B.

Amount of oxygen available as Fe_3O_4 $= A \times \frac{B}{100} \times \frac{64}{168}$

$= 0{\cdot}00381 \times A \times B.$

Per cent reduction: $\frac{\text{Oxygen removed}}{\text{Oxygen available}} \times 100$

$= \frac{0{\cdot}89X \times 100}{A \times B \times 0{\cdot}00381}.$

Cubical specimens of 1 c.m. edge of approximately equal weight were prepared by cutting and grinding the lumps of magnetite ore. Cylindrical briquettes were prepared from the crushed samples using dextrine (1 per cent by weight) as a binding agent with a forming pressure of 5,000 psi. These briquettes were dried at 110° C in an electric oven. These were reduced at various temperatures and gas velocities with hydrogen after preparing cubical specimens from them.

OBSERVATIONS.

1. *Reducibility of the lump ore.*—The samples were reduced with hydrogen at 700, 800 and 900°C for 70 minutes with a hydrogen gas flow of 900 c.c. per minute. Tables I and II indicate the results of the tests carried out on the lump ore cubes.

TABLE I.

Effect of temperature on the rate of reduction of the lump ore.

Rate of flow of hydrogen—900 c.c. per minute.
Total time of reduction—70 minutes.

	Temperature.	Per cent reduction.
1	700°C	50·4
2	800°C	68·6
3	900°C	47·7

TABLE II.

Effect of rate of flow of hydrogen on the rate of reduction of lump ore.

Temperature—900°C.
Total time of reduction—70 minutes.

	Rate of flow of hydrogen.	Per cent reduction.
1	800 c.c. per minute	35·4
2	900 c.c. per minute	47·7
3	1000 c.c. per minute	53·08

It is observed that the reducibility of the ore increased with increase in temperature up to 800°C while at 900°C the per cent reduction is lowered. An increase in gas velocity accelerates the reduction rate at 900°C.

The rate of reduction with the increase of temperature and rate of flow is indicated in Figs. 1 and 2 respectively. It is observed that even though temperature, gas velocity and reduction period increased, per cent reduction or reducibility and the overall per cent reduction never exceeded 70 even after prolonged time of 120 minutes. It has been found that uncrushed lump samples do not give very reproducible results as the different lumps may vary in composition due to the dissemination of the gangue.

2. *Reducibility of the crushed ore samples.*—The next series of experiments was carried out on crushed ore samples in order to get homogeneous mixtures. The tests were conducted with briquettes prepared from different mesh sizes of the crushed iron ore. Results are tabulated in Table III.

TABLE III.

Effect of mesh size on the rate of reduction.

Rate of flow of hydrogen—1,000 c.c./min.
Temperature of reduction—900°C.
Total time of reduction—70 minutes.

	Mesh size.	Per cent reduction.
1	lump ore	53·08
2	—10 mesh	62·0
3	—32 + 72	77·6
4	—100	55·1

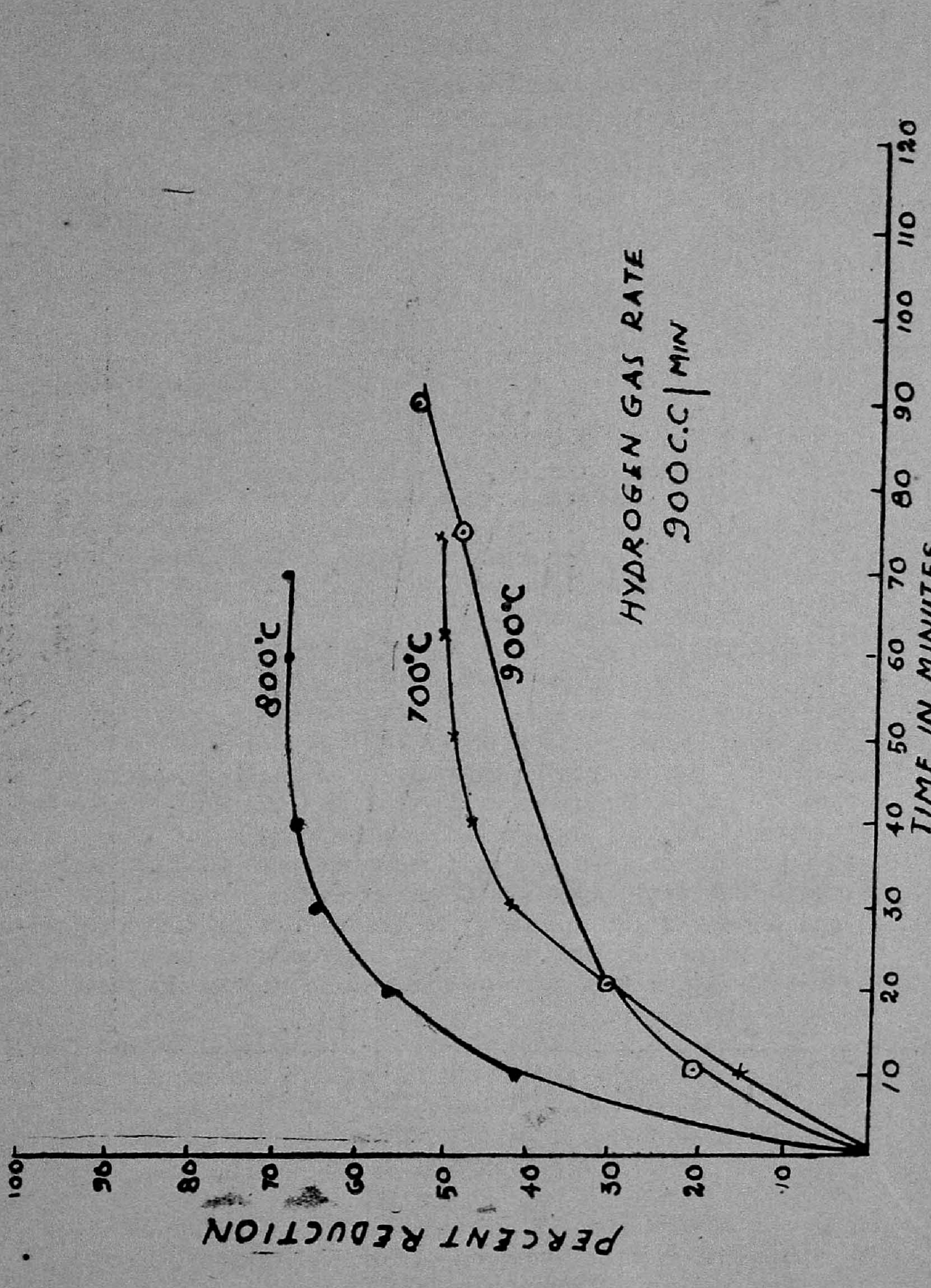


FIG. 1: EFFECT OF TEMPERATURE ON THE RATE OF REDUCTION OF THE LUMP ORE

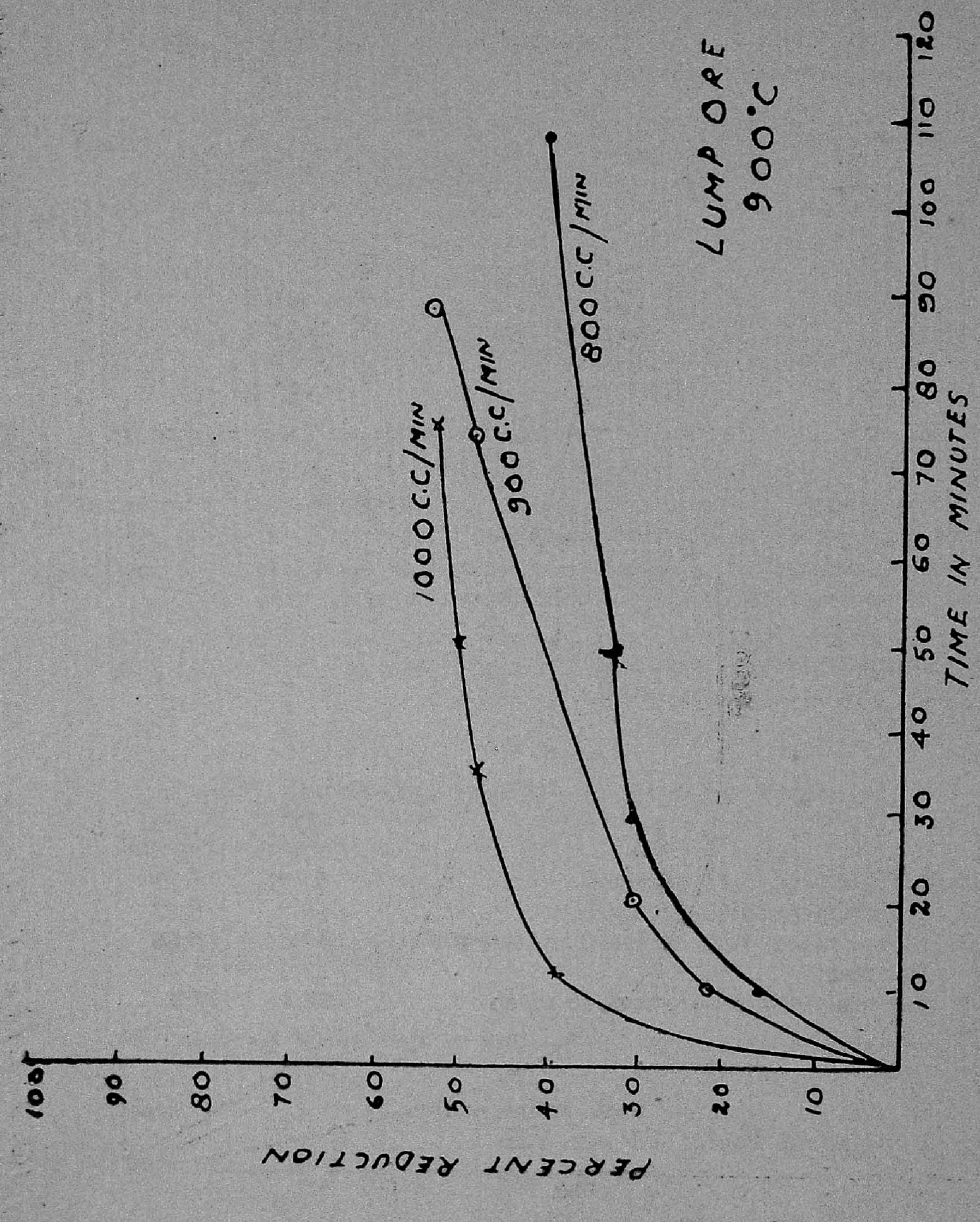


FIG. 2. EFFECT OF HYDROGEN GAS FLOW ON THE RATE OF REDUCTION

Fig. 3 shows the effect of particle size on the rate of reduction of the ore at 900°C and hydrogen gas flow of 1,000 c.c. per minute. It is observed that reducibility has a maximum value of 77·6 per cent for -32 $+72$ mesh sample. It has a lower value at -100 mesh.

Table IV and Fig. 4 indicate that effect of temperature on the per cent reduction of briquettes prepared from $-32+72$ mesh samples (unconcentrated).

TABLE IV.

Effect of temperature on the rate of reduction.

Rate of hydrogen .. .. 1,000 c. c./min.
Total time of reduction .. 70 minutes.

	Temprature °C	Per cent reduction.
1	600	48·5
2	800	59·8
3	900	77·6
4	1,000	69·5

The rate of reduction increases with increase in temperature up to 900°C and then decreases at 1,000°C.

It is clearly observed from Figs. 1, 2, 3 and 4 that optimum mesh size, temperature and gas velocity increase reduction rate during initial period of 20 minutes only but the overall per cent reduction never improved in the unconcentrated ore.

3. *Reducibility tests of the concentrates.*—The composition of the different concentrates obtained in crushing, tabling and magnetic separation, is given in Table V.

TABLE V.

Composition of the different concentrates.

	Fe Per cent.	SiO_2 Per cent.
1 Table concentrate–48 mesh	6 ·68	6·98
2 Table concentrate–65 mesh	68·0	5·33
3 Pilot plant test table concentrate–-48 mesh.	67·0	5·56
4 Wet magnetic separation–48 mesh ..	62·1	13·4

Reducibility tests were carried out in the briquettes obtained from each concentrate.

The results obtained with table concentrate of -48 mesh are tabulated in Tables VI and VII.

TABLE VI.

Effect of temperature on rate of reduction.

Time of reduction .. .. .. 70 minutes.
Rate of Hydrogen gas flow .. 800 c.c./min.
Wt. of concentated ore briquette. 3·6 gms.

	Temperature.	Per cent reduction.
1	700°C	75·9
2	800°C	89·9
3	950°C	95·6
4	1,000°C	93·1

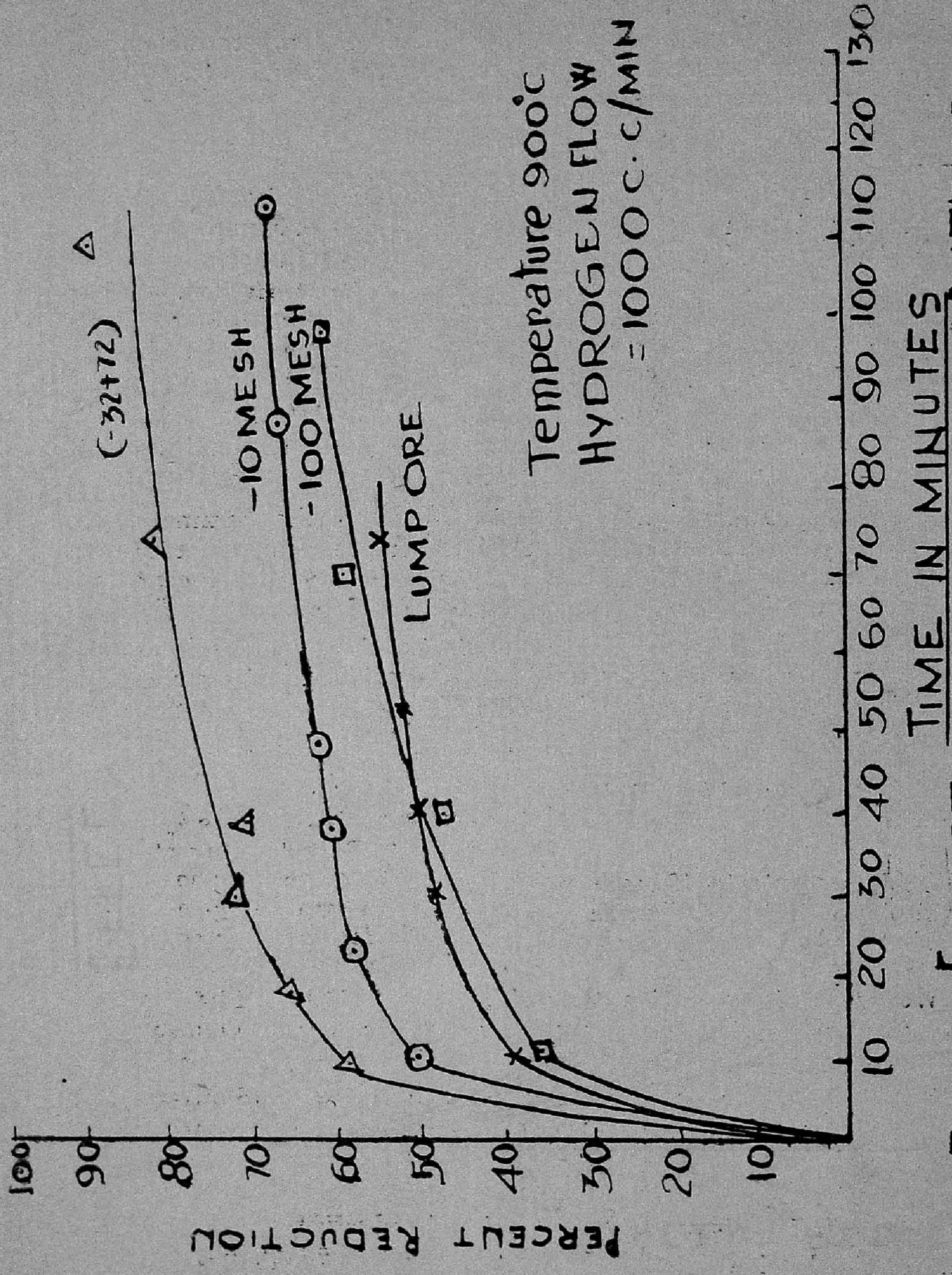


FIG. 3. EFFECT of MESH SIZE ON RATE of REDUCTION ON CRUSHED RAW ORE

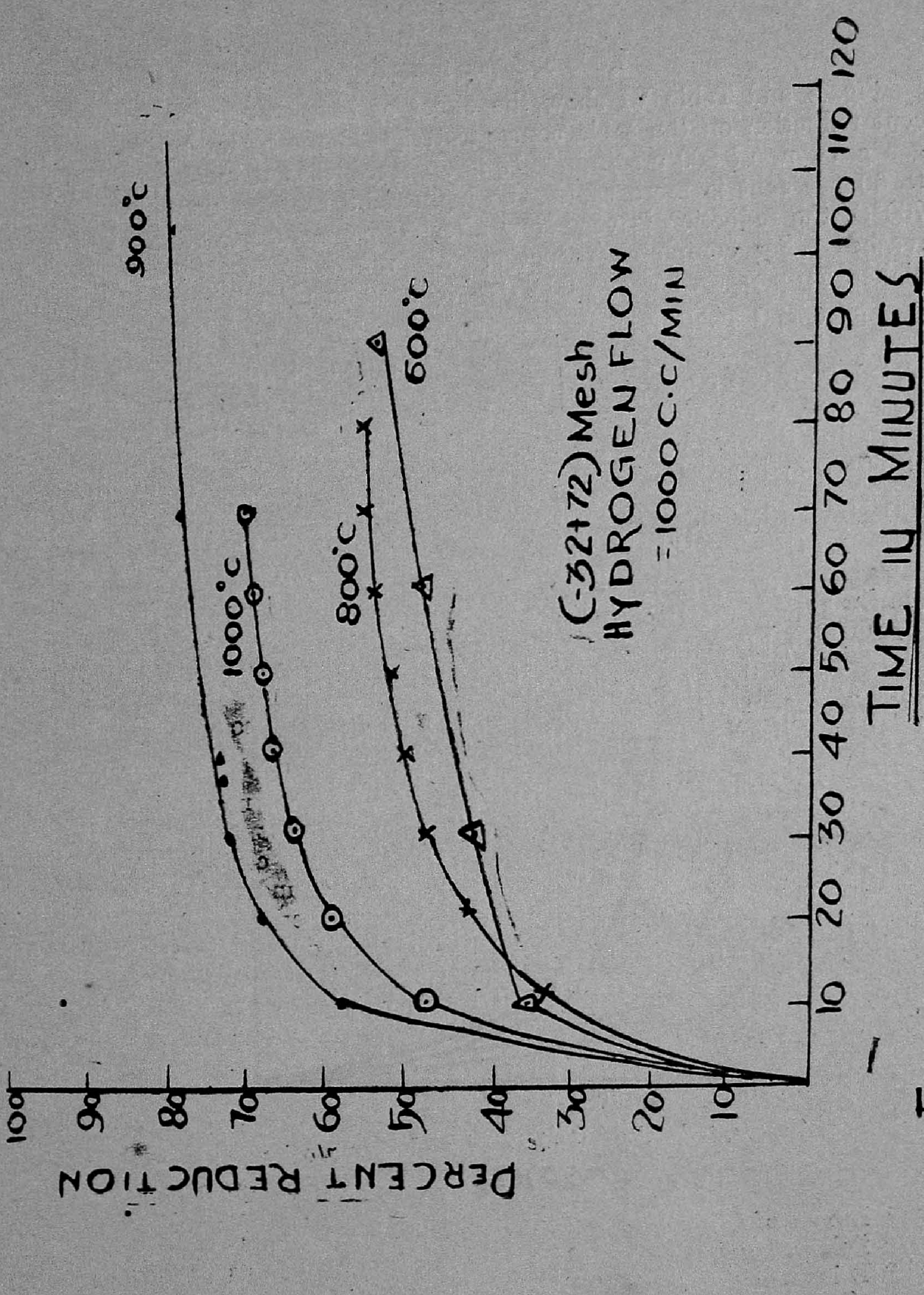


FIG. 4. EFFECT OF TEMPERATURE ON RATE OF REDUCTION

Table VII.

Effect of hydrogen gas flow rate on per cent reduction.

Time of reduction..	70 minutes.
Wt. of concentrated ore briquette ..	3·6 gms.
Temperature of reduction	800 °C.

	Hydrogen gas flow.	Per cent reduction.
1	800 c. c. per minute	89·8
2	900 c. c. per minute	90·6
3	1,000 c. c. per minute	92·4

Fig. 5 and Table VI show the effect of temperature on per cent reduction on the table concentrate (– 48 mesh) for hydrogen gas flow of 800 c.c./min. It is observed that reduction up to 60 per cent is more rapid, the higher the temperature. At 700°C, the reduction is very slow after 60 per cent reduction is reached. For complete reduction of this concentrated ore, higher temperatures above 800°C give good results.

Fig. 6 and Table VII show the effect of rate of gas flow on per cent reduction. At 800°C. the hydrogen gas flow was varied from 600 c.c. to 1,000 c.c. per minute. It was observed that there was an optimum rate of 900 c.c. per minute; increasing the rate beyond 900 c.c. per minute had no practically no effect in increasing reducibility of ore-concentrate.

COMPARISON OF THE REDUCIBILITIES OF THE SALEM MAGNETITE ORE WITH SULAIPET IRON ORE.

Sulaipet iron ore is being used in Indian blast furnaces for producing pig iron and contains Fe_2O_3 84·73 per cent, FeO 12·00 per cent, SiO_2 1.0 per cent, Al_2O_3 0.64 per cent CaO 0.74 per cent, MgO 1.2 per cent P_2O_5 0.04 per cent. This ore, because of its freedom from gangue materials has been taken as a standard for comparing the reducibilities of the magnetite concentrate.

Fig. 7 shows reducibility curves for lump Salem magnetite ore, crushed raw ore, concentrated ore and Sulaipet iron ore. The curves were drawn from the reducibility tests carried out on the above samples at a temperature of 900°C and hydrogen gas rate of 1,000 c.c. per minute. The improvement in reducibility is readily seen in Salem magnetite ore concentrate. It compares well with natural high grade Sulaipet iron ore. The differences in the initial stages of reduction might be due to the porosity of the two different ores. Table VIII shows the apparent density of the ores and concentrates.

Table VIII.

Apparent density of the ores and concentrates.

		Apparent density gms/c.c.
1	Lumps of Salem magnetite ore	3·6
2	Sulaipet ore	4·95
3	Briquette from crushed, unconcentrated Salem magnetite ore.	2·3
4	Briquettes from crushed, concentrated Salem magnetite ore.	3.3

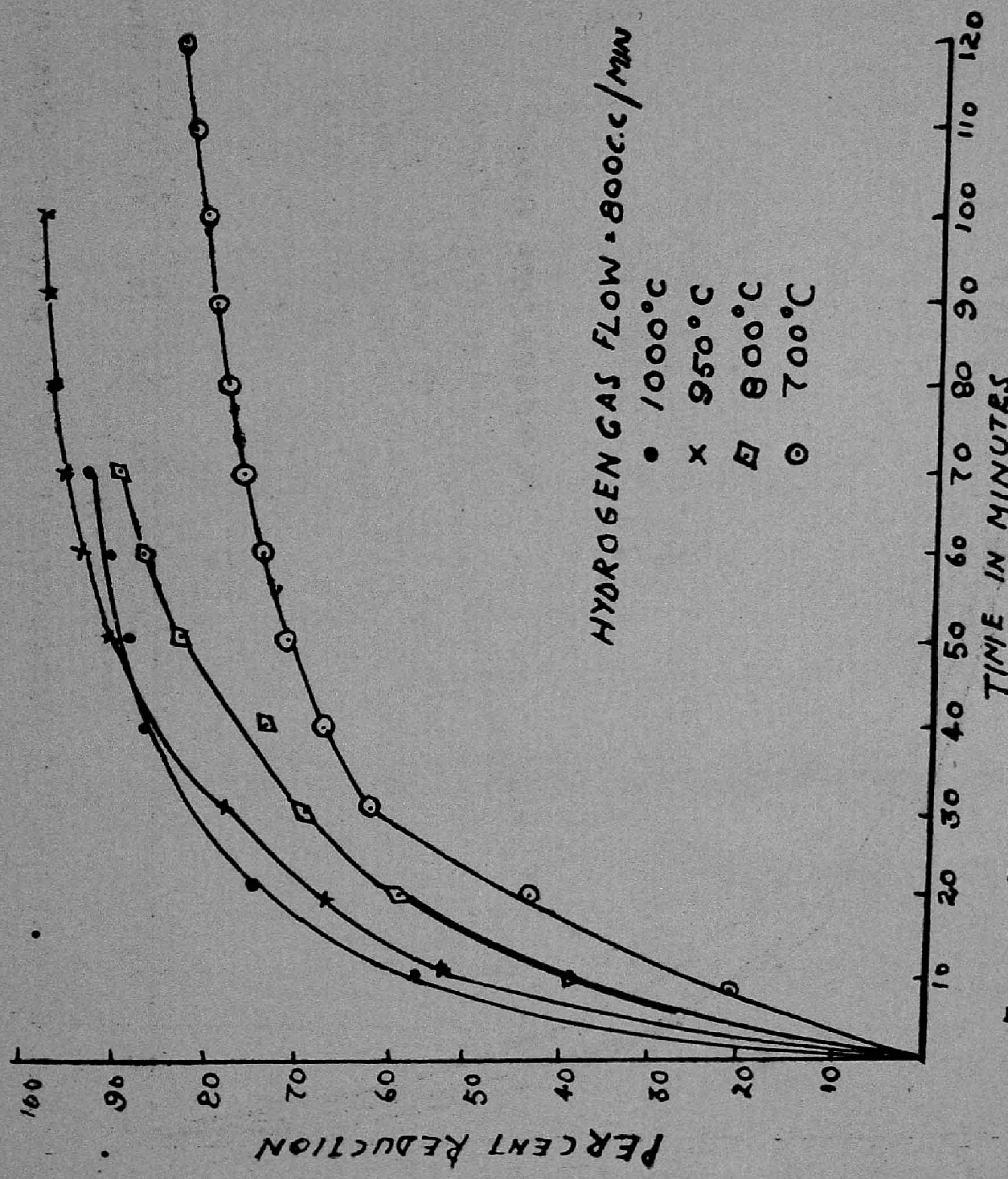


FIG. 5 EFFECT OF TEMPERATURE ON PERCENT REDUCTION.

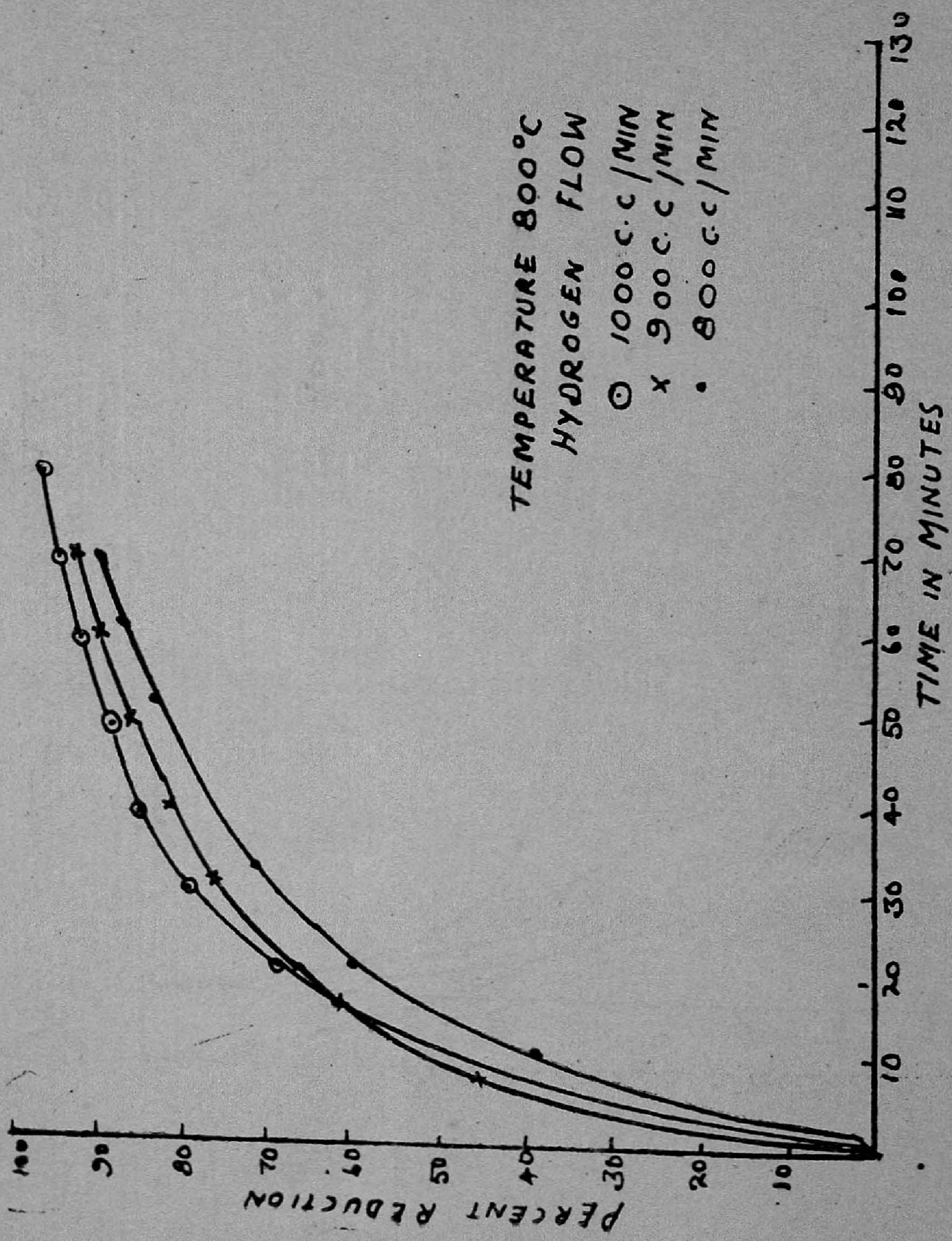


FIG. 6. EFFECT OF HYDROGEN FLOW ON PERCENT REDUCTION.

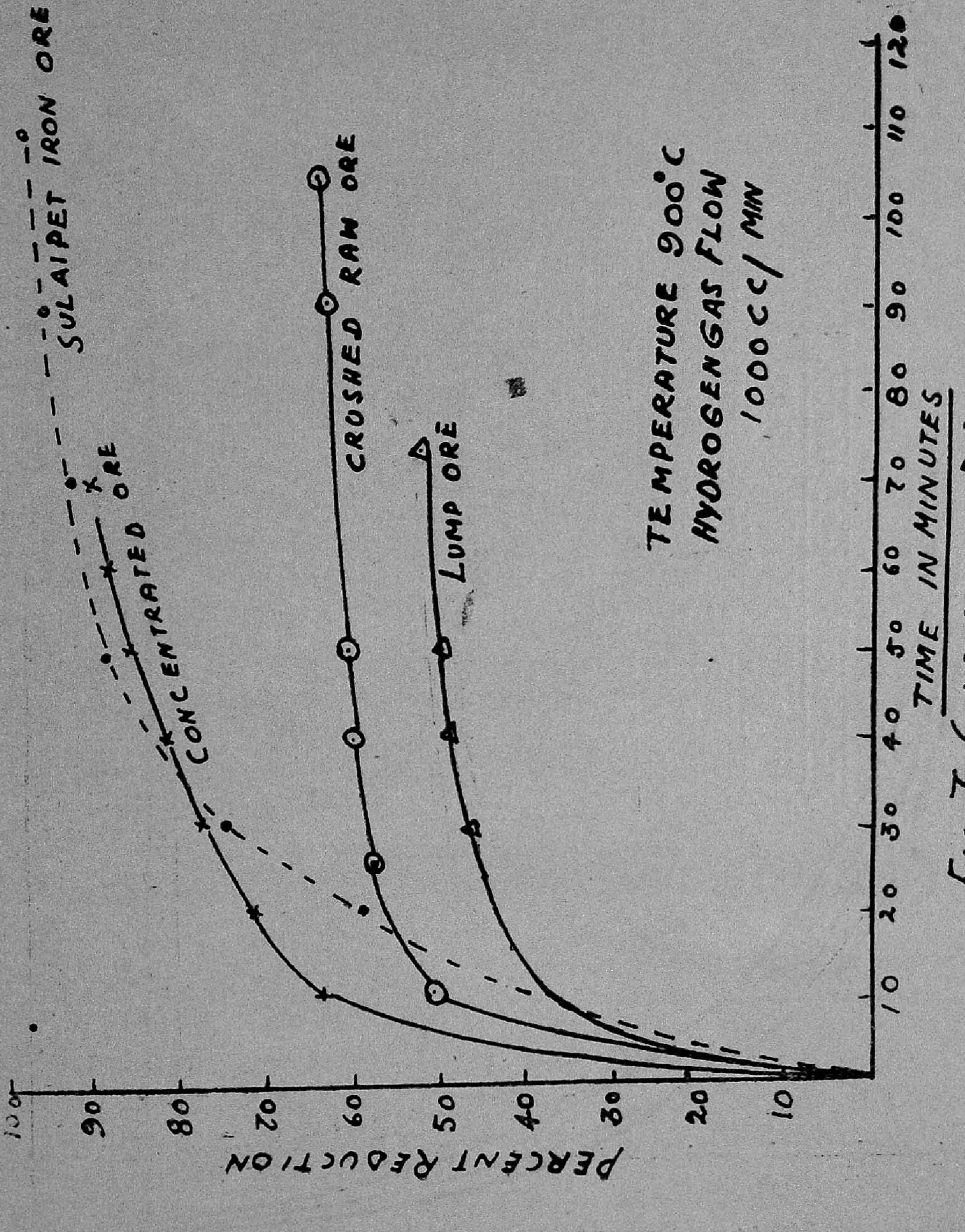


FIG. 7. COMPARISON OF REDUCIBILITIES

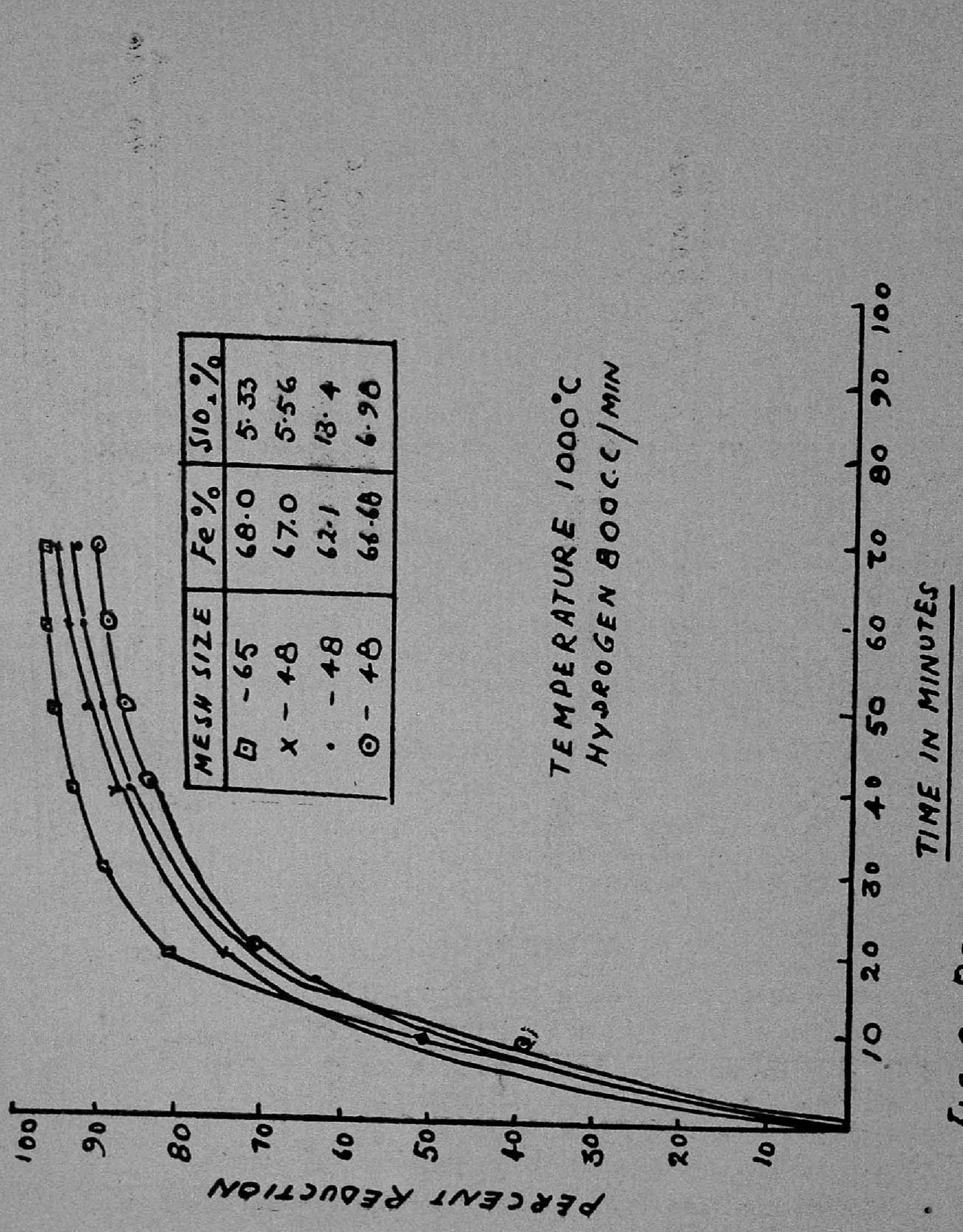


FIG. 8. REDUCIBILITY OF DIFFERENT CONCENTRATES.

Fig. 8 compares the reducibility of different concentrates obtained by (1) and (2) wet magnetic separation. These were reduced by 1,000°C and hydrogen flow of 800 c.c. per minute. It is observed that reducibility of concentrate obtained on wet magnetic separation and containing 13·4 per cent SiO_2 is not materially affected.

Petrographic examination of the reduced lump did not show any fayalite formation. Since the observed improvement in the ore concentrate is due to partial elimination of silica from the raw ore and since in reduction of the raw ore, silica has not combined with iron to form fayalite which might hinder reduction, it is surmised that improvement in the reducibility of the ore concentrate is due to reduction in particle size, increased porosity and gas permeability thereby making the gas diffusion in the gas-solid reaction more efficient.

CONCLUSIONS.

Reducibility tests carried out on the ore concentrates obtained after crushing and tabling and (2) wet magnetic separation indicated that the ore-concentrates obtained possess optimum reducibility. These concentrate after agglomoration could be used for pig iron production in the normal Blast furnace. The product obtained after wet magnetic separation containing 13·4 per cent silica is in no way inferior to the concentrates containing 5·0 to 7·0 per cent silica as far as the reducibility tests are concerned. The high silica will, however, increase the slag volume with its consequent operational difficulties.

ACKNOWLEDGMENT.

The thanks of the authors are due to Dr. B. R. Nijhawan, Director, National Metallurgical Laboratory, for his keen interest and help in the preparation of this report on " Reducibility of Salem Magnetite Ore ".

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APPENDIX V.

(*See* paragraph 41, Chapter V.)

Investigation Report No. I. R. 127/58, dated July 1958 on "Sintering Studies on the Magnetic Concentrate produced from Low Grade Salem Magnetite Ore" by Sarvastree S. K. Banerjee and P. I. A. Narayanan of the National Metallurgical Laboratory, Jamshedpur

ABSTRACT.

Laboratory studies have been made on the sintering characteristics of magnetite concentrate obtained after upgrading of low grade Salem magnetite ore. The effects of variables such as basicity, coke and moisture contents in sinter mix on the sintering time and their effects on the quality of sinter produced, have been studied with a sintering unit designed and fabricated in the laboratory. Research results showed that the optimum amounts of coke and water contents were 7·0 and 9·0 per cent respectively for producing a self-fluxing sinter with a basicity ratio of 0·85.

INTRODUCTION.

The present report forms part III of the investigation and embodies the results of investigation on the sintering characteristics of the concentrates obtained from the low grade Salem magnetite ore. The earlier parts of this work covered (1) the beneficiation characteristics of the ore and (2) reducibility of the ore.

The possibility of using the magnetite concentrate which after upgrading is in the form of fines, for smelting in iron blast furnace or low shaft furnace depends upon the development of a process for agglomarating the fines into lumps. Though there are various methods that could be employed for the purpose, viz., briquetting, pelletising, sintering, etc., the last, i.e., sintering appears to be most promising for this ore particularly since the final sinter will be in the form of a more easily reducible product than magnetite itself which is known to be more difficult to reduce and smelt.

Sintering consists essentially of the combustion of a mixture of ore and fuel on a down-draught grate. It not only converts the constituents into an agglomerate but also yields a self-flushing burden for iron-making.

A good sinter can be a perfect agglomerate if it is uniform in composition, is porous and readily reducible. The production of a good sinter depends upon to a large extent on two main factors (*a*) Coke or fuel content of the charge which controls the sintering temperature in the bed, (*b*) permeability of the bed which controls the air-flow through the bed.

The amount of coke required to attain requisite sintering temperature and optimum sintering rate normally varies from 6·7 per cent. Sinter quality usually improves with increased carbon up to an optimum figure beyond which no improvement results. Below the critical value of carbon a soft product with much unsintered material results, while excess of carbon increases the sintering temperature, thereby melting the charge which produces a sinter characterised by large voids, glazed surfaces and reduced porosity.

Additions other than ore and fuel are often made with a view to controlling special properties of sinter.

Addition of limestone is advantageous in obtaining self-fluxing sinter. It also inhibits the formation of difficulty reducible fayalite. However, excess of limestone may result in the formation of calcium ferrite which is also not easily reduced in the iron blast furnace.

The grade and properties of raw materials, their sizing method of mixing and laying the bed are some of the most important factors affecting the permeability of the bed.

Moisture content is very important in securing proper porosity of the bed. Optimum water content is necessary for uniform balling of the charge. Too much water causes difficulty in burning of the mix whereas with too little of it, the porous nature of the bed cannot be maintained due to resulting compacting of the bed.

In the preparation of sinter charge, it is the practice to charge in the mix some sinter fines obtained as rejects after screening the coarse sinter for the blast furnace. The addition of sinter fines increases the porosity of the mix and reduces the sintering time. Thus, the quantity of fuel, the moisture content, grade and size of the product forming of the charge, method of mixing the charge, loose and uniform charging, proper ignition and ensuring enough supply of air are essential conditions which must be precisely defined to control sintering.

RAW MATERIALS.

Magnetite concentrate.—The sample of low grade magnetite received from Salem in South India assayed 36·5 per cent total Fe, 5·04 per cent FeO, 44·2 per cent SiO_2, 1·92 per cent Al_2O_3, 1·8 per cent CaO, 0·9 per cent MgO and 0·09 per cent P. The concentrate obtained by magnetic separation of the ground ore at the pilot plant of the Department of Atomic Energy at Ghatsila, was employed for these tests. The exact procedure followed for the production of the concentrate is described in part I of the report covering the beneficiation of the ore. The Chemical and Sieve analyses the concentrate are given in Tables 1 and 2 respectively.

TABLE 1.

Chemical analysis.

Constituent.	Per cent.
Total Fe	62·1
FeO	13·1
SiO_2	13·2
Al_2O_3	1·12
MgO	0·7
CaO	1·0
P	0·081
S	0·35

NOTE.—No responsibility is taken for the results except in so for as they apply to the raw materials tested.

Sieves referred to in the report are from the Tylor's standard sieve series.

TABLE 2.

Sieve analysis.

Size (mesh).	Weight PER CENT
+65	12·6
−65+100	14·4
−100+150	17·3
−150+200	10.5
−200	45·2
	100·0

Limestone.—The limestone used for sintering was received from the Indian Bureau of Mines in connection with the studies made earlier on the sintering of Bhilai iron ore fines. The limestone sample was crushed to − 10 mesh in jaw and roll crushers. The chemical and sieve analysis of the sample are given in Tables 3 and 4.

TABLE 3.

Chemical analysis.

Constituent.	Per cent.
CaO	49·26
SiO_2	3·79
Al_2O_3	0·66
MgO	2·64
Loss on ignition.	41·89

TABLE 4.

Sieve analysis.

Size (mesh)	Weight PER CENT.
−10+28	35·5
−20+28	17·2
−28+35	11·3
−35+48	8·5
−48+65	6·0
−65+100	4·5
−100+150	3·2
−150+200	2·0
−200	11·8
	100·0

Coke.—The coke breeze which was obtained locally was crushed to −8 mesh as before. The chemical and sieve analyses of coke are given in Tables 5 and 6.

TABLE 5.

Chemical analysis.

Constituent.	Per cent.
SiO_2	11·6
Al_2O_3	6·2
CaO	1·0
MgO	0·5
Fixed C	76·1
Ash	22·4
P	0·16

TABLE 6.

Sieve analysis.

Size (mesh).	Weight per cent.
− 8+10	23·3
−10+14	20·1
−14+20	14·1
−20+28	10·6
−28+35	8·0
−35+48	6·1
−48+65	4·9
−65+100	3·7
−100+150	3·0
−150+200	2·3
−200	3·9
	100·0

EXPERIMENTAL PROCEDURE.

The tests were carried out in a Batch sintering unit capacity 40 lb. designed and fabricated in the National Metallurgical Laboratory. It has a grate of size 8 inches square and operates at 20 inches w.g. (suction). It consists of a combustion chamber with gas burner, a sinter box with two cast iron grates one above the other and a lower chamber. The lower chamber is connected by pipe to a fan having a suction capacity of 1,300 c.ft. of air per minute at N.T.P. The air pipe is provided with a butterfly valve to control suction. The fan is driven by a 10 h.p. motor.

Preparation of the mix and sinter bed.—The sinter mix weighing about 35 lbs. was made up of the magnetite concentrate, limestone, coke, water and sinter fines. A typical charge is given in Table 7.

TABLE 7.

Composition of sinter mix.

	LBS.
Concentrate	17·5
Coke	2·5
Limestone	4·5
Water	3·5
Sinter fines	7·0
	35·0

The proportions of limestone, coke and water were varied one at a time to determine their optimum requirements. Of the 7 lbs. of sinter fines used in the mix, 2 lbs. of coarse fraction ($-\frac{1}{2}'' + \frac{1}{4}''$) was spread as a bottom layer over the grate to prevent the latter's overheating. Regarding coke, about 0·5 lbs. of it was kept aside and mixed with top 1″ layer of the mix to facilitate uniform burning during ignition. Thus the sinter bed consisted of 3 distinct layers of material, viz., (1) the bottom $\frac{1}{2}''$ layer of coarse sinter fines, (2) middle layer $7\frac{1}{2}''$ thick with medium amount of coke and (3) top 1″ layer richer in coke, making a total bed of thickness 9″.

Ignition.—Coke oven gas was used for igniting the top layer. The time of ignition was $1\frac{1}{2}$ minutes at a gas pressure of 12″ w.g. The suction during ignition was kept at 12″–15″ w.g., as measured by means of a water manometer connected to the lower chamber. After ignition, the ignition chamber was swung aside and the suction increased to 20″ w.g. by fully opening the butterfly valve. The suction dropped to 17″ w.g. after sintering was completed. The temperature of the exhaust gases just below the furnace grates was measured by means of a chromel-alumel thermo-couple. This temperature gradually increased as

sintering proceeded, reached a maximum and then started falling. Completion of sintering was indicated by this fall in temperature. The sinter was air-cooled, weighed and broken to $-\frac{1}{4}''$ size for shatter and tumbler tests.

Physical tests for sinter.—As no standard tests have been laid down for determining the strength of sinter, the following procedure was adopted for the shatter and tumbler tests:—

For the shatter test, 16 lb. of the $-4'' + 1''$ size sinter were dropped twice from a height of 6 feet on a M.S. plate. The shatter product was sieve analysed to find out the size stability and percentage weight of $-\frac{1}{4}''$ material produced. The procedure was similar to that followed for determining the size stability of coal.

For the tumbler tests, 5 lb. of the $-1'' + \frac{1}{4}''$ size material subjected to shatter test were tumbled for 200 revolutions at the rate of 25 revolutions per minute. The tumbled products were sieve analysed and the percentage of $+\frac{1}{4}''$ and -20 mesh material noted.

EXPERIMENTAL RESULTS.

Effect of variation in basicity on sintering.—A series of tests was performed changing the basicity of the charge by control of limestone addition, but maintaining the come and water contents at 7 and 10 per cent respectively. The basicity ratio $\frac{CaO + MgO}{SiO_2 + Al_2O_3}$ was varied from 0·6 to 1·2 to determine the basicity at which a good sinter could be produced. The results are given in Table 8.

The results showed that the time of sintering decreased with increase in limestone content of the charge indicating that sintering was inversely proportional to the basicity ratio. The strength of sinter was maximum at a basicity ratio of 0·75 and it dropped gradually with further increase in basicity. Taking into consideration the sinter strength and time of sintering, a basicity ratio of 0·85 was taken an optimum for satisfactory sinter.

TABLE 8.

Effect of variation in basicity on sintering.

Total weight of mix.	Per cent with respect to mix: Per cent water.	Per cent coke.	Per cent lime-stone.	Per cent sinter fines.	Time of sintering in mts.	Temp °C.	Suction wg: Max.	Min.	Percent wt. of -5/8 in-4" sinter with respect to sinter.	Shatter size stability.	wight 0-¼" after shatter,	Tumbler test: per cent. +¼"	per cent. -20 mesh	Basicity ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
25 lbs.	10·0	7·0	6·0	20·0	24	305	20·0	17·5	21·1	53·0	8·1	92·5	1·7	.6
Do.	Do.	7·0	10·0	Do.	23½	370	20·0	17·5	24·4	66·9	6·5	94·2	1·5	·75
Do.	Do.	7·0	13·0	Do.	23·0	315	20·25	17.25	25·0	64·9	7·6	90.8	2·0	·85
Do.	Do.	Do.	15·5	Do.	22·0	300	20·0	16·5	26·0	55·74	7·8	91·7	1·8	·95
Do.	Do.	Do.	19·0	Do.	20·0	385	20·5	16·5	26·0	43·9	10·0	91·5	1·8	1·2

TABLE 9.

Effect of variation of coke contents on sintering.

Total weight of mix.	Per cent with respect to mix: Per cent. water.	Per cent. coke.	Per cent, lime-stone	Per cent. sinter fines	Time of sintering in mts.	Temp. °C	Suction w.g.: max.	min,	Per cent weight of -5/8 in-4" sinter (with respect to sinter)	Shatter size stability.	Percent. of 4" after shatter.	Tumbler test: Per cent. +¼"	Per cent, -20 mesh	Basicity ratio,
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
35 lbs. ..	10·0	5·5	13·0	20·0	28	140	20·5	17·0	No sinter					
Do. ..	Do.	6·0	Do.	Do.	26	250	20·5	Do.	29·0	54·1	7·6	90·1	2·2	0·85
Do. ..	Do.	6·5	Do.	Do.	25	348	Do.	17·5	27·0	61·9	8·3	92·5	1·7	Do.
Do. ..	Do.	7·0	Do.	Do.	23	315	Do.	17·25	25·0	64·9	7·6	90.8	2·0	Do.
Do. ..	Do.	7·5	Do.	Do.	20·5	420	20·0	17·0	20·0	57·2	6.0	93·1	1·5	Do.

Effect of variation of coke on sintering.—The coke content of the charge was then varied from 5·5 to 7·5 per cent keeping the basicity ratio at 0·85 by requisite additions of limestone. The water content of the mix was kept as before at 10 per cent. The results are given in Table 9.

The results showed that sintering time decreased with increase in coke contents. With lower quantity of coke, the amount of unsintered material was high. The optimum amount of coke necessary to produce the best sinter was found to be 7 per cent. Sinter produced with 7·5 per cent coke had equally good strength but got slightly fused and lacked porosity.

Effect of variation of water on sintering.—A number of tests were performed varying the water contents in the mix and maintaining a basicity of 0·85 and coke content at 7·0 per cent. The addition of water was varied from 7 to 10·5 per cent of the mix. Table 10 gives the results of the test.

The sintering time increased with the increase in water content. The time of sintering was 21 minutes with a water content of 9·0 per cent. Considering both time and strength, this was taken as optimum. With less water the charge did not ball up properly to give the required permeability in the bed during sintering.

Effect of variation of sinter fines.—The amount of sinter fines produced during the tests varied between 6·5 to 7·0 lbs. which represented about 20 per cent by weight of the mix. However, a few sinter samples were made by increasing the percentage of sinter fines in the charge. The results are given in Table 11.

The time of sintering decreased with increase in the percentage of sinter fines. This was due to higher porosity of the charge. The strength of sinter decreased slightly with the increase in sinter fines.

Other tests.—A few tests were carried out varying the suction during sintering. Lowering of suction increased the time of sintering without any improvement in the quality of the sinter.

When the coke content of the top layer of the sinter bed was reduced, the strength of sinter deteriorated. There was no appreciable change in the time of sintering.

Keeping in view the shortage of coal in South India, a few sinter were made using charcoal as a fuel but without success. The burning of charcoal was too fast to produce any sinter.

Table 10.

Effect of variation of water contents oh sinterig.

Total weight of mix.	Per cent with respect to mix. Per cent water.	Per cent coke.	Per cent lime-stonc.	Per cent sinter fines.	Time of sintering in mts.	Temp. °C	Suction w.g. Max.	Min.	Percent weight of —5/8" in —4" inter (with respect to sinter.)	Shatter size stabi-lity.	Per cent weight of -¼" after shatter.	Tumbler test Per cent + ¼	Per cent —20 mesh.	Basi-city ratio.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
351 lb.	7·0	7·0	13·0	20·0	17	415	20·5	17·0	28·0	46·1	8·4	93·0	1·5	0·85
Do.	8·0	Do.	Do.	Dc.	17	418	20·25	17·0	24·0	47·4	8·0	94·1	1·5	Do.
Do.	9·0	Do.	Do.	Do.	21	320	20·5	17·5	25·0	61·2	6·2	93·1	1·8	Do.
Do.	10·0	Do.	Do.	Do.	23	315	20·25	17·26	25·0	64·9	7·6	90·8	2·0	Do.
Do,	10·5	Do.	Do.	Do.	24	400	20·5	17·5	33·0	58·4	8,5	91·4	1.5	Do.

Table 11.

Effect of variation in contents of sinter fides,

Total weight of mix.	Per cent with respect to mix. per cent water.	per cent coke.	Per cent lime-stone.	Per cent sinter fines.	of ing in mts.	Temp. °C.	Suction w.g. Max.	Min.	Per cent weight of —51"8 in -4" sinter(with respect or inter.)	Shatter size stabi-lity.	per cent weight of -¼" after shatter.	Tumbler test. Per cent + ¼"	Per cent — 20 mesh.	Basi-city ratio.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
35 lbs.	10.0	7·0	13·0	20·0	23	315	20·25	17·25	25·0	64·9	7·6	90·8	2·0	0·85
Do.	Do.	Do.	Do.	23·0	22	400	20·0	17·0	23·0	60·0	7·6	90·0	2·1	Do.
Do.	Do.	Do.	Do.	25·0	21	400	20·0	17·0	23.5	56·6	6.8	92·1	1·8	Do.

Chemical analysis of a few sinter samples.

Constituents.	Sinter with ·6 basicity.	Sinter with 0·85 basicity.	Sinter with 1·2 basicity.
Total Fe	54·4	53·68	50·72
FeO	28·92	25·12	25·81
CaO	7·52	9·76	12·70
MgO	0·41	1·52	0·92
SiO_2	12·43	13·25	13·1
Al_2O_3	0.74	1·38	0·87
P	..	0·071	..
S	..	·115	..
Calculated basicity	·61	·81	1·0

SUMMARY AND CONCLUSION.

Laboratory studies have been made on the sintering of magnetite concentrate obtained by magnetite separation of the low grade Salem magnetite ore. The sinter mix consisted of the magnetite concentrate, limestone, coke, water and sinter fines.

Coke, water and limestone were varied to obtain the best sinter. The basicity $\frac{CaO+MgO}{SiO_2+Al\ O_3}$ of the charge was varied from to 1·2 by varying the limestone content of the charge. The time of sintering decreased with increase in limestone contents of the charge. Taking into consideration both time and strength, a basicity ratio of 0·85 was found to be optimum for satisfactory sinter.

It was observed that the time of sintering decreased with increase in coke content. The amount of coke necessary to produce the best sinter was found to be 7 per cent. Higher coke content in the charge produced fused sinters.

Sintering time increased with increase in water content of the charge. The time of sintering was 21 minutes for a water content of 9 per cent in the mix. Considering both time and strength, this was taken as optimum.

Thus, the optimum time of sintering was 21 minutes for a charge with a basicity ratio of 0·85 and with 7·0 per cent coke and 9·0 per cent water.

Sintering time varied inversely with suction. Increase in the quantity of sinter fines over 20 per cent was found to reduce the sintering time but the sinter strength was lower.

The sinters produced during the tests were found to be strongly magnetic, containing mostly magnetite with some hematite embedded in a matrix of slag.

The top of the sinter was always found to be more friable than either the middle or the bottom lowers.

ACKNOWLEDGMENT.

The thanks of the investigators are due to Dr. B. R. Nijhawan, Director, National Metallurgical Laboratory, for his keen interest in the investigation and to Shri B. B. Mondal for chemical analyses.

APPENDIX VI.

See PARGRAPH 63. CHAPTER V.

Benefication of Low Grade Magnetite from Salem, Madras. List of equipment required for a beneficiation plant of caqacity 200 tons of ore per day of 24 hours and estimates of working and capital costs by Sarvashree S. K. Banerjee and P. I. A. Narayanan.

As desired by the Government of Madras, a flow sheet for a continuous plant of capacity 200 tons of magnetite ore per day of 24 hours as well as an estimate of capital and working costs are presented below. The flow sheet has been drawn on the basis of the results obtained in the laboratory with the sample received from Salem. (Vide I.R. No.116/58 Jan. 1958). A plant treating 200 tons of ore per day will produce about 100 tons of magnetite concentrate every day.

List of equipments required for a plant of capacity 200 tons of ore per day of 24 hours.

Serial number.	*Name of the item.*	*Capacity.*	*Size.*	*No.*	*H. P.*
	A-Crushing.				
1	Ore hopper	25 tons	..	1	..
2	Jaw crusher	25 tons/hr.	10″×24″	1	40
3	Apron feeder	25 tons/hr.	30″×10′	1	5
4	Guard magnet	..	24″	1	
5	Double deck Vibrating Screen with 1″×3/8″ screens.	25 tons/hr.	3′×8′	1	2
6	Belt conveyor	25 tons/hr	24″×75′	1	10
7	Cone crusher ..	20 tons/hr	3′	1	75
8	Fine ore bin	200 tons	..	1	..
9	Vpron Feeder ..	8·5 tons/hr	24″×10′	1	5
10	Sampler	24″ Simlex Denver sampler	..	1	0·5
11	Weightometer ..	..	..	1	..
	B-Grinding and magnetic separation.				
12	Rod mill	8·5 tons/hr.	6′×8′	1	175
13	Crossflow Classifier ..	8·5 tons/hs	20·9″×54″	1	3
14	Pump	8·5 tons/hr	3″ Duplex	1	3
15	Cone feeder	8·5 tons/hr	.	1	..
16	Wet magnetic Separator (Low intensity)	.. 8·5 tons/hr	24″magnet × 30″ Belt	1 / 1	.. / 3
17	Wet magnetic Separator (High intensity)	..	12″ magnet × 18″ belt	1	3
18	Pumps	4·5 tons/hr each	32 simplex	2	6
19	Thickener	4·5 tons/hs	36′×10′	1	2
20	Disc filters with vaccum equipments ..	4·5 tons/hr	6′×10 di ce	2 units.	10
21	Belt Conveyor ..	4·5 tons/hr	18″×50′	1	7·5
22	Dryer	4·5 tons/hr	45″×40′	1	15

B-Grinding anā magnutic seperation—cont.

Serial number and name of the item.	*Capacity.*	*Size.*	*No.*	*H. P.*
23 Sampler	24″ Denver simplex sampler		2	1
24 Weightometer ..			1	..
25 Belt Conveyor ..	4·5 tons/hr	24″ × 100′	1	15
26 Concentrate Bin ..	100 tons	..	2	..
C—Briquetting and Hardening.				
27 Bins for tar and pitch ..	10 tons	24″ × 100′	2	..
28 Bins for coke and fluxes. ..	50 tons	..	2	..
29 Belt Convayor ..	4·5 tons/hr	24″ × 100′	1	15
30 Mixer	4·5 tons/hr	..	1 }	
31 Feeder	4·5 tons/hr	24″ × 10′	1 }	10
32 Briquetting machine	4·5 tons/hr	..	1 }	
33 Belt Conveyor ..	4·5 tons/hr	18″ × 20′	1	5
34 Hardening Furnace	4·5 tons/hr	60″ × 40′	1	..
35 Belt Conveyor ..	4·5 tons/hr	24″ × 50′	1	7·5
36 Storage Bin for .. Briquettes	400 tons	..	..	..
			Total H. P.	423·5

Approximate cost of machinery will be as follows:—

	RS.
A—Crushing—Item 1 to 11	4,20,000
B—Grinding and Magnetic separation—Item 12 to 26.	9,10,000
C—Briquetting and hardening—Item 27 to 86.	4,10,000
	17,40,000

Estimated cost of plant:—

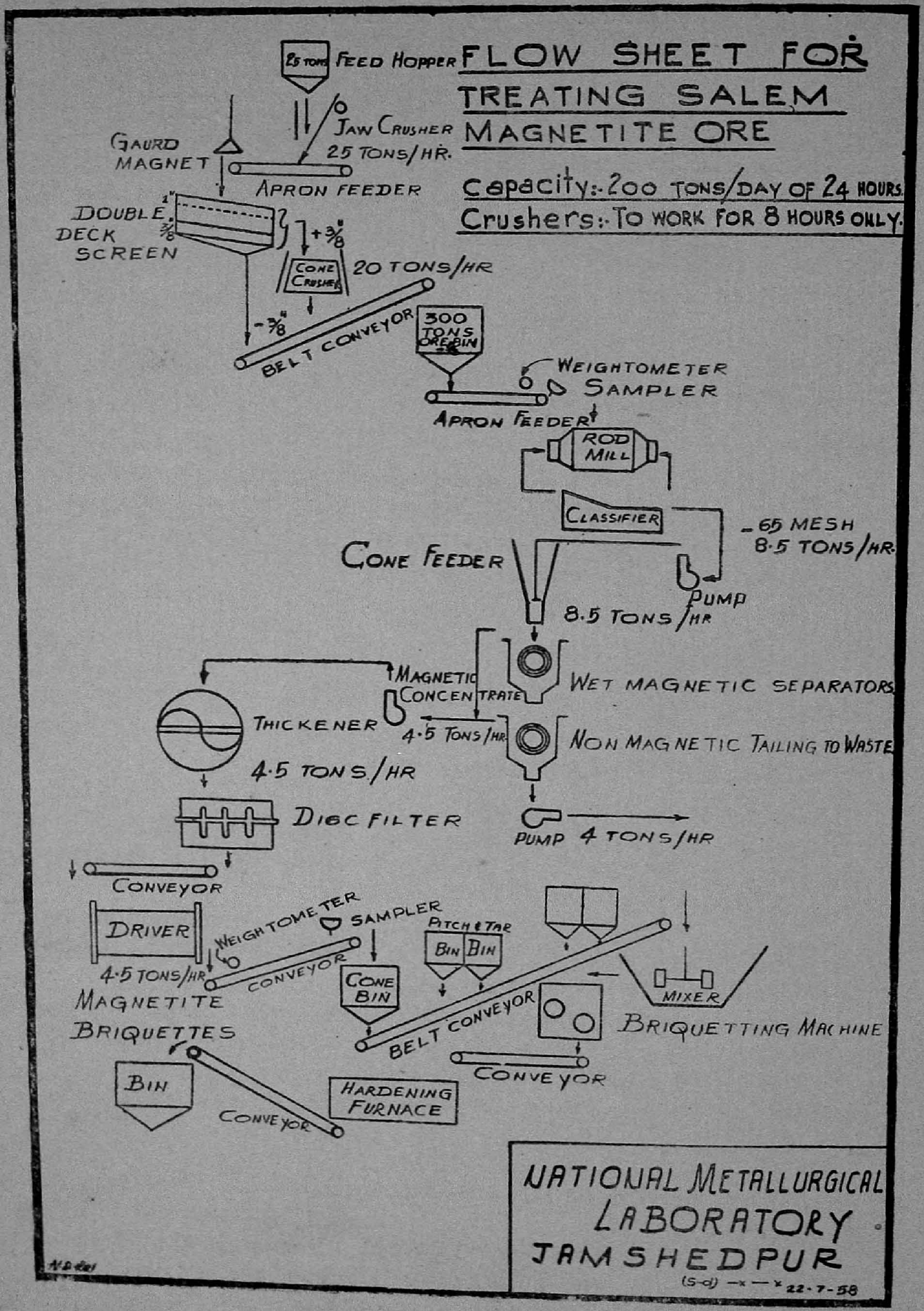
	RS.
Machinary	17,40,000
Railway freight. transport insurance etc.	1,50,000
Mill, laboratory, workshop .. .. .. } Office bulding etc. (30,000 sq. ft. at Rs. 12 }	3,60,000
Platforms, launders etc, ...	1,00,000
Foundations, supply of power, and water etc.	3,00,000
Erection of equipment and machinery	1,50,000
Contingencies and incidentals	3,00.000
Grand Total	31,00,000

Approximate cost of beneficiation

	Rupees per ton of raw ore	Rupees per ton of concentrate (Assumig 2 tons of ore = 1 ton of conc.
Crushing and Screening ..	1·00	..
Secondary crushing and grinding. ..	2·00	
Magnatic Seperation ..	0·60	
	Rs. 3·60	Rs, 7·20
Drying and briquetting	..	7·50
		14·70
Cost of mining	10·00	20·00
Depreciation at 7 per cent on the Capital outlay ..	..	7·00
	Total cost	41·70
	or	42·00

The crushing section (Section A) has been designed to work only for 8 hours per day for the present so that, doubling the capacity to 400 tons will need only an increase in working hours to 16.

Sections B and C have been designed to work for 24 hours and it is expected that an additional amount of Rs. 10–12 lakhs will be necessary for increasing the plant capacity to 400 tons per day.


FLOW SHEET FOR TREATING SALEM MAGNETITE ORE
Capacity:- 200 TONS/DAY OF 24 HOURS.
Crushers:- TO WORK FOR 8 HOURS ONLY.
25 TONS FEED HOPPER
JAW CRUSHER 25 TONS/HR.
GAURD MAGNET
APRON FEEDER
DOUBLE DECK SCREEN
1"
3/8"
+3/8"
-3/8"
CONE CRUSHER
20 TONS/HR
BELT CONVEYOR
300 TONS ORE BIN
WEIGHTOMETER
SAMPLER
APRON FEEDER
ROD MILL
CLASSIFIER
-65 MESH 8.5 TONS/HR.
CONE FEEDER
PUMP
8.5 TONS/HR
MAGNETIC CONCENTRATE
WET MAGNETIC SEPARATORS
THICKENER
4.5 TONS/HR
NON MAGNETIC TAILING TO WASTE
4.5 TONS/HR
DISC FILTER
PUMP 4 TONS/HR
CONVEYOR
DRIVER
4.5 TONS/HR
WEIGHTOMETER
SAMPLER
CONVEYOR
PITCH & TAR
BIN
BIN
CONE BIN
MAGNETITE BRIQUETTES
BELT CONVEYOR
MIXER
BRIQUETTING MACHINE
CONVEYOR
BIN
CONVEYOR
HARDENING FURNACE
NATIONAL METALLURGICAL LABORATORY JAMSHEDPUR
(S-d) —x —x 22-7-58

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